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on

SURFACE EXPRESSION LIBRARIES  
OF RANDOMIZED PEPTIDES

by

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SURFACE EXPRESSION LIBRARIES  
OF RANDOMIZED PEPTIDES

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BACKGROUND OF THE INVENTION

This invention relates generally to methods for synthesizing and expressing oligonucleotides and, more particularly, to methods for expressing oligonucleotides having random codon sequences.

10 Oligonucleotide synthesis proceeds via linear coupling of individual monomers in a stepwise reaction. The reactions are generally performed on a solid phase support by first coupling the 3' end of the first monomer to the support. The second monomer is added to the 5'  
15 end of the first monomer in a condensation reaction to yield a dinucleotide coupled to the solid support. At the end of each coupling reaction, the by-products and unreacted, free monomers are washed away so that the starting material for the next round of synthesis is the  
20 pure oligonucleotide attached to the support. In this reaction scheme, the stepwise addition of individual monomers to a single, growing end of a oligonucleotide ensures accurate synthesis of the desired sequence.  
Moreover, unwanted side reactions are eliminated, such as  
25 the condensation of two oligonucleotides, resulting in high product yields.

In some instances, it is desired that synthetic oligonucleotides have random nucleotide sequences. This result can be accomplished by adding equal proportions of  
30 all four nucleotides in the monomer coupling reactions, leading to the random incorporation of all nucleotides and yielding a population of oligonucleotides with random

sequences. Since all possible combinations of nucleotide sequences are represented within the population, all possible codon triplets will also be represented. If the objective is ultimately to generate random peptide products, this approach has a severe limitation because the random codons synthesized will bias the amino acids incorporated during translation of the DNA by the cell into polypeptides.

The bias is due to the redundancy of the genetic code. There are four nucleotide monomers which leads to sixty-four possible triplet codons. With only twenty amino acids to specify, many of the amino acids are encoded by multiple codons. Therefore, a population of oligonucleotides synthesized by sequential addition of monomers from a random population will not encode peptides whose amino acid sequence represents all possible combinations of the twenty different amino acids in equal proportions. That is, the frequency of amino acids incorporated into polypeptides will be biased toward those amino acids which are specified by multiple codons.

To alleviate amino acid bias due to the redundancy of the genetic code, the oligonucleotides can be synthesized from nucleotide triplets. Here, a triplet coding for each of the twenty amino acids is synthesized from individual monomers. Once synthesized, the triplets are used in the coupling reactions instead of individual monomers. By mixing equal proportions of the triplets, synthesis of oligonucleotides with random codons can be accomplished. However, the cost of synthesis from such triplets far exceeds that of synthesis from individual monomers because triplets are not commercially available.

Amino acid bias can be reduced, however, by synthesizing the degenerate codon sequence NNK where N is a mixture of all four nucleotides and K is a mixture 5 guanine and thymine nucleotides. Each position within an oligonucleotide having this codon sequence will contain a total of 32 codons (12 encoding amino acids being represented once, 5 represented twice, 3 represented three times and one codon being a stop codon).

Oligonucleotides expressed with such degenerate codon 10 sequences will produce peptide products whose sequences are biased toward those amino acids being represented more than once. Thus, populations of peptides whose sequences are completely random cannot be obtained from oligonucleotides synthesized from degenerate sequences.

15 There thus exists a need for a method to express oligonucleotides having a fully random or desirably biased sequence which alleviates genetic redundancy. The present invention satisfies these needs and provides additional advantages as well.

20 SUMMARY OF THE INVENTION

The invention provides a plurality of prokaryotic cells containing a diverse population of expressible oligonucleotides operationally linked to expression elements, the expressible oligonucleotides having a 25 desirable bias of random codon sequences.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing for synthesizing oligonucleotides from nucleotide monomers with random triplets at each position using twenty reaction vessels.

Figure 2 is a schematic drawing for synthesizing oligonucleotides from nucleotide monomers with random triplets at each position using ten reaction vessels.

Figure 3 is a schematic diagram of the two vectors used for sublibrary and library production from precursor oligonucleotide portions. M13IX22 (Figure 3A) is the vector used to clone the anti-sense precursor portions (hatched box). The single-headed arrow represents the Lac p/o expression sequences and the double-headed arrow represents the portion of M13IX22 which is to be combined with M13IX42. The amber stop codon for biological selection and relevant restriction sites are also shown. M13IX42 (Figure 3B) is the vector used to clone the sense precursor portions (open box). Thick lines represent the pseudo-wild type ( $\Psi$ gVIII) and wild type (gVIII) gene VIII sequences. The double-headed arrow represents the portion of M13IX42 which is to be combined with M13IX22. The two amber stop codons and relevant restriction sites are also shown. Figure 3C shows the joining of vector population from sublibraries to form the functional surface expression vector M13IX. Figure 3D shows the generation of a surface expression library in a non-suppressor strain and the production of phage. The phage are used to infect a suppressor strain (Figure 3E) for surface expression and screening of the library.

Figure 4 is a schematic diagram of the vector used for generation of surface expression libraries from random oligonucleotide populations (M13IX30). The symbols are as described for Figure 3.

Figure 5 is the nucleotide sequence of M13IX42 (SEQ ID NO: 1).

*Sub  
C2  
CONT.*

Figure 6 is the nucleotide sequence of M13IX22 (SEQ ID NO: 2).

Figure 7 is the nucleotide sequence of M13IX30 (SEQ ID NO: 3).

5 Figure 8 is the nucleotide sequence of M13ED03 (SEQ ID NO: 4).

Figure 9 is the nucleotide sequence of M13IX421 (SEQ ID NO: 5).

10 Figure 10 is the nucleotide sequence of M13ED04 (SEQ ID NO: 6).

#### DETAILED DESCRIPTION OF THE INVENTION

This invention is directed to a simple and inexpensive method for synthesizing and expressing oligonucleotides having a desirable bias of random codons using individual monomers. The method is advantageous in that individual monomers are used instead of triplets and by synthesizing only a non-degenerate subset of all triplets, codon redundancy is alleviated. Thus, the oligonucleotides synthesized represent a large proportion of possible random triplet sequences which can be obtained. The oligonucleotides can be expressed, for example, on the surface of filamentous bacteriophage in a form which does not alter phage viability or impose biological selections against certain peptide sequences.

20 The oligonucleotides produced are therefore useful for generating an unlimited number of pharmacological and research products.

In one embodiment, the invention entails the sequential coupling of monomers to produce oligonucleotides with a desirable bias of random codons. The coupling reactions for the randomization of twenty codons which specify the amino acids of the genetic code are performed in ten different reaction vessels. Each reaction vessel contains a support on which the monomers for two different codons are coupled in three sequential reactions. One of the reactions couples an equal mixture of two monomers such that the final product has two different codon sequences. The codons are randomized by removing the supports from the reaction vessels and mixing them to produce a single batch of supports containing all twenty codons at a particular position.

Synthesis at the next codon position proceeds by equally dividing the mixed batch of supports into ten reaction vessels as before and sequentially coupling the monomers for each pair of codons. The supports are again mixed to randomize the codons at the position just synthesized.

The cycle of coupling, mixing and dividing continues until the desired number of codon positions have been randomized. After the last position has been randomized, the oligonucleotides with random codons are cleaved from the support. The random oligonucleotides can then be expressed, for example, on the surface of filamentous bacteriophage as gene VIII-peptide fusion proteins. Alternative genes can be used as well.

In its broadest form, the invention provides a diverse population of synthetic oligonucleotides contained in vectors so as to be expressible in cells. Such populations of diverse oligonucleotides can be fully random at one or more codon sites or can be fully defined at one or more site, so long as at least one site the codons are randomly variable. The populations of oligonucleotides can be expressed as fusion products in

combination with surface proteins of filamentous bacteriophage, such as M13, as with gene VIII. The vectors can be transfected into a plurality of cells, such as the procaryote E. coli.

5       The diverse population of oligonucleotides can be formed by randomly combining first and second precursor populations, each precursor population having a desirable bias of random codon sequences. Methods of synthesizing and expressing the diverse population of expressible  
10 oligonucleotides are also provided.

In a preferred embodiment, two populations of random oligonucleotides are synthesized. The oligonucleotides within each population encode a portion of the final oligonucleotide which is to be expressed.

15 Oligonucleotides within one population encode the carboxy terminal portion of the expressed oligonucleotides. These oligonucleotides are cloned in frame with a gene VIII (gVIII) sequence so that translation of the sequence produces peptide fusion proteins. The second population  
20 of oligonucleotides are cloned into a separate vector. Each oligonucleotide within this population encodes the anti-sense of the amino terminal portion of the expressed oligonucleotides. This vector also contains the elements necessary for expression. The two vectors containing the  
25 random oligonucleotides are combined such that the two precursor oligonucleotide portions are joined together at random to form a population of larger oligonucleotides derived from two smaller portions. The vectors contain selectable markers to ensure maximum efficiency in  
30 joining together the two oligonucleotide populations. A mechanism also exists to control the expression of gVIII-peptide fusion proteins during library construction and screening.

As used herein, the term "monomer" or "nucleotide monomer" refers to individual nucleotides used in the chemical synthesis of oligonucleotides. Monomers that can be used include both the ribo- and deoxyribo- forms  
5 of each of the five standard nucleotides (derived from the bases adenine (A or dA, respectively), guanine (G or dG), cytosine (C or dC), thymine (T) and uracil (U)). Derivatives and precursors of bases such as inosine which are capable of supporting polypeptide biosynthesis are  
10 also included as monomers. Also included are chemically modified nucleotides, for example, one having a reversible blocking agent attached to any of the positions on the purine or pyrimidine bases, the ribose or deoxyribose sugar or the phosphate or hydroxyl  
15 moieties of the monomer. Such blocking groups include, for example, dimethoxytrityl, benzoyl, isobutyryl, beta-cyanoethyl and diisopropylamine groups, and are used to protect hydroxyls, exocyclic amines and phosphate  
moieties. Other blocking agents can also be used and are  
20 known to one skilled in the art.

As used herein, the term "tuplet" refers to a group of elements of a definable size. The elements of a tuplet as used herein are nucleotide monomers. For example, a tuplet can be a dinucleotide, a trinucleotide  
25 or can also be four or more nucleotides.

As used herein, the term "codon" or "triplet" refers to a tuplet consisting of three adjacent nucleotide monomers which specify one of the twenty naturally occurring amino acids found in polypeptide biosynthesis.  
30 The term also includes nonsense, or stop, codons which do not specify any amino acid.

"Random codons" or "randomized codons," as used herein, refers to more than one codon at a position within a collection of oligonucleotides. The number of different codons can be from two to twenty at any particular position. "Randomized oligonucleotides," as used herein, refers to a collection of oligonucleotides with random codons at one or more positions. "Random codon sequences" as used herein means that more than one codon position within a randomized oligonucleotide contains random codons. For example, if randomized oligonucleotides are six nucleotides in length (i.e., two codons) and both the first and second codon positions are randomized to encode all twenty amino acids, then a population of oligonucleotides having random codon sequences with every possible combination of the twenty triplets in the first and second position makes up the above population of randomized oligonucleotides. The number of possible codon combinations is  $20^2$ . Likewise, if randomized oligonucleotides of fifteen nucleotides in length are synthesized which have random codon sequences at all positions encoding all twenty amino acids, then all triplets coding for each of the twenty amino acids will be found in equal proportions at every position. The population constituting the randomized oligonucleotides will contain  $20^{15}$  different possible species of oligonucleotides. "Random triplets," or "randomized triplets" are defined analogously.

As used herein, the term "bias" refers to a preference. It is understood that there can be degrees of preference or bias toward codon sequences which encode particular amino acids. For example, an oligonucleotide whose codon sequences do not preferably encode particular amino acids is unbiased and therefore completely random. The oligonucleotide codon sequences can also be biased toward predetermined codon sequences or codon frequencies

and while still diverse and random, will exhibit codon sequences biased toward a defined, or preferred, sequence. "A desirable bias of random codon sequences" as used herein, refers to the predetermined degree of 5 bias which can be selected from totally random to essentially, but not totally, defined (or preferred). There must be at least one codon position which is variable, however.

As used herein, the term "support" refers to a solid 10 phase material for attaching monomers for chemical synthesis. Such support is usually composed of materials such as beads of control pore glass but can be other materials known to one skilled in the art. The term is also meant to include one or more monomers coupled to the 15 support for additional oligonucleotide synthesis reactions.

As used herein, the terms "coupling" or "condensing" refers to the chemical reactions for attaching one monomer to a second monomer or to a solid support. Such 20 reactions are known to one skilled in the art and are typically performed on an automated DNA synthesizer such as a MilliGen/Bioscience Cyclone Plus Synthesizer using procedures recommended by the manufacturer. "Sequentially coupling" as used herein, refers to the 25 stepwise addition of monomers.

A method of synthesizing oligonucleotides having random triplets using individual monomers is described. The method consists of several steps, the first being synthesis of a nucleotide triplet for each triplet to be 30 randomized. As described here and below, a nucleotide triplet (i.e., a codon) will be used as a specific example of a triplet. Any size triplet will work using the methods disclosed herein, and one skilled in the art

would know how to use the methods to randomize triplets of any size.

If the randomization of codons specifying all twenty amino acids is desired at a position, then twenty different codons are synthesized. Likewise, if randomization of only ten codons at a particular position is desired then those ten codons are synthesized. Randomization of codons from two to sixty-four can be accomplished by synthesizing each desired triplet. Preferably, randomization of from two to twenty codons is used for any one position because of the redundancy of the genetic code. The codons selected at one position do not have to be the same codons selected at the next position. Additionally, the sense or anti-sense sequence oligonucleotide can be synthesized. The process therefore provides for randomization of any desired codon position with any number of codons.

Codons to be randomized are synthesized sequentially by coupling the first monomer of each codon to separate supports. The supports for the synthesis of each codon can, for example, be contained in different reaction vessels such that one reaction vessel corresponds to the monomer coupling reactions for one codon. As will be used here and below, if twenty codons are to be randomized, then twenty reaction vessels can be used in independent coupling reactions for the first twenty monomers of each codon. Synthesis proceeds by sequentially coupling the second monomer of each codon to the first monomer to produce a dimer, followed by coupling the third monomer for each codon to each of the above-synthesized dimers to produce a trimer (Figure 1, step 1, where  $M_1$ ,  $M_2$  and  $M_3$  represent the first, second and third monomer, respectively, for each codon to be randomized).

Following synthesis of the first codons from individual monomers, the randomization is achieved by mixing the supports from all twenty reaction vessels which contain the individual codons to be randomized.

5 The solid phase support can be removed from its vessel and mixed to achieve a random distribution of all codon species within the population (Figure 1, step 2). The mixed population of supports, constituting all codon species, are then redistributed into twenty independent  
10 reaction vessels (Figure 1, step 3). The resultant vessels are all identical and contain equal portions of all twenty codons coupled to a solid phase support.

For randomization of the second position codon, synthesis of twenty additional codons is performed in  
15 each of the twenty reaction vessels produced in step 3 as the condensing substrates of step 1 (Figure 1, step 4). Steps 1 and 4 are therefore equivalent except that step 4 uses the supports produced by the previous synthesis cycle (steps 1 through 3) for codon synthesis whereas  
20 step 1 is the initial synthesis of the first codon in the oligonucleotide. The supports resulting from step 4 will each have two codons attached to them (i.e., a hexanucleotide) with the codon at the first position being any one of twenty possible codons (i.e., random)  
25 and the codon at the second position being one of the twenty possible codons.

For randomization of the codon at the second position and synthesis of the third position codon, steps 2 through 4 are again repeated. This process yields in  
30 each vessel a three codon oligonucleotide (i.e., 9 nucleotides) with codon positions 1 and 2 randomized and position three containing one of the twenty possible codons. Steps 2 through 4 are repeated to randomize the third position codon and synthesize the codon at the next

position. The process is continued until an oligonucleotide of the desired length is achieved. After the final randomization step, the oligonucleotide can be cleaved from the supports and isolated by methods known 5 to one skilled in the art. Alternatively, the oligonucleotides can remain on the supports for use in methods employing probe hybridization.

The diversity of codon sequences, i.e., the number of different possible oligonucleotides, which can be 10 obtained using the methods of the present invention, is extremely large and only limited by the physical characteristics of available materials. For example, a support composed of beads of about 100  $\mu\text{m}$  in diameter will be limited to about 10,000 beads/reaction vessel 15 using a 1  $\mu\text{M}$  reaction vessel containing 25 mg of beads. This size bead can support about  $1 \times 10^7$  oligonucleotides per bead. Synthesis using separate reaction vessels for each of the twenty amino acids will produce beads in which all the oligonucleotides attached to an individual 20 bead are identical. The diversity which can be obtained under these conditions is approximately  $10^7$  copies of  $10,000 \times 20$  or 200,000 different random oligonucleotides. The diversity can be increased, however, in several ways without departing from the basic methods disclosed 25 herein. For example, the number of possible sequences can be increased by decreasing the size of the individual beads which make up the support. A bead of about 30  $\mu\text{m}$  in diameter will increase the number of beads per reaction vessel and therefore the number of 30 oligonucleotides synthesized. Another way to increase the diversity of oligonucleotides with random codons is to increase the volume of the reaction vessel. For example, using the same size bead, a larger volume can contain a greater number of beads than a smaller vessel 35 and therefore support the synthesis of a greater number

of oligonucleotides. Increasing the number of codons coupled to a support in a single reaction vessel also increases the diversity of the random oligonucleotides. The total diversity will be the number of codons coupled 5 per vessel raised to the number of codon positions synthesized. For example, using ten reaction vessels, each synthesizing two codons to randomize a total of twenty codons, the number of different oligonucleotides of ten codons in length per 100  $\mu\text{m}$  bead can be increased 10 where each bead will contain about  $2^{10}$  or  $1 \times 10^3$  different sequences instead of one. One skilled in the art will know how to modify such parameters to increase the diversity of oligonucleotides with random codons.

A method of synthesizing oligonucleotides having 15 random codons at each position using individual monomers wherein the number of reaction vessels is less than the number of codons to be randomized is also described. For example, if twenty codons are to be randomized at each position within an oligonucleotide population, then ten 20 reaction vessels can be used. The use of a smaller number of reaction vessels than the number of codons to be randomized at each position is preferred because the smaller number of reaction vessels is easier to manipulate and results in a greater number of possible 25 oligonucleotides synthesized.

The use of a smaller number of reaction vessels for random synthesis of twenty codons at a desired position within an oligonucleotide is similar to that described above using twenty reaction vessels except that each 30 reaction vessel can contain the synthesis products of more than one codon. For example, step one synthesis using ten reaction vessels proceeds by coupling about two different codons on supports contained in each of ten reaction vessels. This is shown in Figure 2 where each

of the two codons coupled to a different support can consist of the following sequences: (1) (T/G)TT for Phe and Val; (2) (T/C)CT for Ser and Pro; (3) (T/C)AT for Tyr and His; (4) (T/C)GT for Cys and Arg; (5) (C/A)TG for Leu and Met; (6) (C/G)AG for Gln and Glu; (7) (A/G)CT for Thr and Ala; (8) (A/G)AT for Asn and Asp; (9) (T/G)GG for Trp and Gly and (10) A(T/A)A for Ile and Cys. The slash (/) signifies that a mixture of the monomers indicated on each side of the slash are used as if they were a single monomer in the indicated coupling step. The antisense sequence for each of the above codons can be generated by synthesizing the complementary sequence. For example, the antisense for Phe and Val can be AA(C/A). The amino acids encoded by each of the above pairs of sequences are given as the standard three letter nomenclature.

Coupling of the monomers in this fashion will yield codons specifying all twenty of the naturally occurring amino acids attached to supports in ten reaction vessels. However, the number of individual reaction vessels to be used will depend on the number of codons to be randomized at the desired position and can be determined by one skilled in the art. For example, if ten codons are to be randomized, then five reaction vessels can be used for coupling. The codon sequences given above can be used for this synthesis as well. The sequences of the codons can also be changed to incorporate or be replaced by any of the additional forty-four codons which constitutes the genetic code.

The remaining steps of synthesis of oligonucleotides with random codons using a smaller number of reaction vessels are as outlined above for synthesis with twenty reaction vessels except that the mixing and dividing steps are performed with supports from about half the

number of reaction vessels. These remaining steps are shown in Figure 2 (steps 2 through 4).

Oligonucleotides having at least one specified tuplet at a predetermined position and the remaining 5 positions having random triplets can also be synthesized using the methods described herein. The synthesis steps are similar to those outlined above using twenty or less reaction vessels except that prior to synthesis of the specified codon position, the dividing of the supports 10 into separate reaction vessels for synthesis of different codons is omitted. For example, if the codon at the second position of the oligonucleotide is to be specified, then following synthesis of random codons at the first position and mixing of the supports, the mixed 15 supports are not divided into new reaction vessels but, instead, can be contained in a single reaction vessel to synthesize the specified codon. The specified codon is synthesized sequentially from individual monomers as described above. Thus, the number of reaction vessels 20 can be increased or decreased at each step to allow for the synthesis of a specified codon or a desired number of random codons.

Following codon synthesis, the mixed supports are divided into individual reaction vessels for synthesis of 25 the next codon to be randomized (Figure 1, step 3) or can be used without separation for synthesis of a consecutive specified codon. The rounds of synthesis can be repeated for each codon to be added until the desired number of positions with predetermined or randomized codons are 30 obtained.

Synthesis of oligonucleotides with the first position codon being specified can also be synthesized using the above method. In this case, the first position

codon is synthesized from the appropriate monomers. The supports are divided into the required number of reaction vessels needed for synthesis of random codons at the second position and the rounds of synthesis, mixing and 5 dividing are performed as described above.

A method of synthesizing oligonucleotides having tuples which are diverse but biased toward a predetermined sequence is also described herein. This method employs two reaction vessels, one vessel for the 10 synthesis of a predetermined sequence and the second vessel for the synthesis of a random sequence. This method is advantageous to use when a significant number of codon positions, for example, are to be of a specified sequence since it alleviates the use of multiple reaction 15 vessels. Instead, a mixture of four different monomers such as adenine, guanine, cytosine and thymine nucleotides are used for the first and second monomers in the codon. The codon is completed by coupling a mixture of a pair of monomers of either guanine and thymine or 20 cytosine and adenine nucleotides at the third monomer position. In the second vessel, nucleotide monomers are coupled sequentially to yield the predetermined codon sequence. Mixing of the two supports yields a population of oligonucleotides containing both the predetermined 25 codon and the random codons at the desired position. Synthesis can proceed by using this mixture of supports in a single reaction vessel, for example, for coupling additional predetermined codons or, further dividing the mixture into two reaction vessels for synthesis of 30 additional random codons.

The two reaction vessel method can be used for codon synthesis within an oligonucleotide with a predetermined tuple sequence by dividing the support mixture into two portions at the desired codon position to be randomized.

Additionally, this method allows for the extent of randomization to be adjusted. For example, unequal mixing or dividing of the two supports will change the fraction of codons with predetermined sequences compared to those with random codons at the desired position. Unequal mixing and dividing of supports can be useful when there is a need to synthesize random codons at a significant number of positions within an oligonucleotide of a longer or shorter length.

The extent of randomization can also be adjusted by using unequal mixtures of monomers in the first, second and third monomer coupling steps of the random codon position. The unequal mixtures can be in any or all of the coupling steps to yield a population of codons enriched in sequences reflective of the monomer proportions.

Synthesis of randomized oligonucleotides is performed using methods well known to one skilled in the art. Linear coupling of monomers can, for example, be accomplished using phosphoramidite chemistry with a MilliGen/Bioscience Cyclone Plus automated synthesizer as described by the manufacturer (Millipore, Burlington, MA). Other chemistries and automated synthesizers can be employed as well and are known to one skilled in the art.

Synthesis of multiple codons can be performed without modification to the synthesizer by separately synthesizing the codons in individual sets of reactions. Alternatively, modification of an automated DNA synthesizer can be performed for the simultaneous synthesis of codons in multiple reaction vessels.

In one embodiment, the invention provides a plurality of prokaryotic cells containing a diverse population of expressible oligonucleotides operationally linked to expression elements, the expressible 5 oligonucleotides having a desirable bias of random codon sequences produced from diverse combinations of first and second oligonucleotides having a desirable bias of random sequences. The invention provides for a method for constructing such a plurality of prokaryotic cells as 10 well.

The oligonucleotides synthesized by the above methods can be used to express a plurality of random peptides which are unbiased, diverse but biased toward a predetermined sequence or which contain at least one 15 specified codon at a predetermined position. The need will determine which type of oligonucleotide is to be expressed to give the resultant population of random peptides and is known to one skilled in the art. Expression can be performed in any compatible vector/host 20 system. Such systems include, for example, plasmids or phagemids in prokaryotes such as E. coli, yeast systems, and other eucaryotic systems such as mammalian cells, but will be described herein in context with its presently preferred embodiment, i.e. expression on the surface of 25 filamentous bacteriophage. Filamentous bacteriophage can be, for example, M13, f1 and fd. Such phage have circular single-stranded genomes and double strand replicative DNA forms. Additionally, the peptides can also be expressed in soluble or secreted form depending 30 on the need and the vector/host system employed.

Expression of random peptides on the surface of M13 can be accomplished, for example, using the vector system shown in Figure 3. Construction of the vectors enabling one of ordinary skill to make them are explicitly set out

in Examples I and II. The complete nucleotide sequences are given in Figures 5, 6 and 7 (SEQ ID NOS: 1, 2 and 3, respectively). This system produces random oligonucleotides functionally linked to expression 5 elements and to gVIII by combining two smaller oligonucleotide portions contained in separate vectors into a single vector. The diversity of oligonucleotide species obtained by this system or others described herein can be  $5 \times 10^7$  or greater. Diversity of less than 10  $5 \times 10^7$  can also be obtained and will be determined by the need and type of random peptides to be expressed. The random combination of two precursor portions into a larger oligonucleotide increases the diversity of the population several fold and has the added advantage of 15 producing oligonucleotides larger than what can be synthesized by standard methods. Additionally, although the correlation is not known, when the number of possible paths an oligonucleotide can take during synthesis such as described herein is greater than the number of beads, 20 then there will be a correlation between the synthesis path and the sequences obtained. By combining oligonucleotide populations which are synthesized separately, this correlation will be destroyed. Therefore, any bias which may be inherent in the 25 synthesis procedures will be alleviated by joining two precursor portions into a contiguous random oligonucleotide.

Populations of precursor oligonucleotides to be combined into an expressible form are each cloned into 30 separate vectors. The two precursor portions which make up the combined oligonucleotide corresponds to the carboxy and amino terminal portions of the expressed peptide. Each precursor oligonucleotide can encode either the sense or anti-sense and will depend on the 35 orientation of the expression elements and the gene

encoding the fusion portion of the protein as well as the mechanism used to join the two precursor oligonucleotides. For the vectors shown in Figure 3, precursor oligonucleotides corresponding to the carboxy 5 terminal portion of the peptide encode the sense strand. Those corresponding to the amino terminal portion encode the anti-sense strand. Oligonucleotide populations are inserted between the Eco RI and Sac I restriction enzyme sites in M13IX22 and M13IX42 (Figure 3A and B). M13IX42 10 (SEQ ID NO: 1) is the vector used for sense strand precursor oligonucleotide portions and M13IX22 (SEQ ID NO: 2) is used for anti-sense precursor portions.

The populations of randomized oligonucleotides inserted into the vectors are synthesized with Eco RI and 15 Sac I recognition sequences flanking opposite ends of the random codon sequences. The sites allow annealing and ligation of these single strand oligonucleotides into a double stranded vector restricted with Eco RI and Sac I. Alternatively, the oligonucleotides can be inserted into 20 the vector by standard mutagenesis methods. In this latter method, single stranded vector DNA is isolated from the phage and annealed with random oligonucleotides having known sequences complementary to vector sequences. The oligonucleotides are extended with DNA polymerase to 25 produce double stranded vectors containing the randomized oligonucleotides.

The vector used for sense strand oligonucleotide portions, M13IX42 (Figure 3B) contains down-stream and in frame with the Eco RI and Sac I restriction sites a 30 sequence encoding the pseudo-wild type gVIII product. This gene encodes the wild type M13 gVIII amino acid sequence but has been changed at the nucleotide level to reduce homologous recombination with the wild type gVIII contained on the same vector. The wild type gVIII is

present to ensure that at least some functional, non-fusion coat protein will be produced. The inclusion of a wild type gVIII therefore reduces the possibility of non-viable phage production and biological selection against 5 certain peptide fusion proteins. Differential regulation of the two genes can also be used to control the relative ratio of the pseudo and wild type proteins.

Also contained downstream and in frame with the Eco RI and Sac I restriction sites is an amber stop codon.

10 The mutation is located six codons downstream from Sac I and therefore lies between the inserted oligonucleotides and the gVIII sequence. As was the function of the wild type gVIII, the amber stop codon also reduces biological selection when combining precursor portions to produce 15 expressible oligonucleotides. This is accomplished by using a non-suppressor (<sup>sup</sup> O) host strain because non-suppressor strains will terminate expression after the oligonucleotide sequences but before the pseudo gVIII sequences. Therefore, the pseudo gVIII will never be 20 expressed on the phage surface under these circumstances. Instead, only soluble peptides will be produced.

Expression in a non-suppressor strain can be advantageously utilized when one wishes to produce large populations of soluble peptides. Stop codons other than 25 amber, such as opal and ochre, or molecular switches, such as inducible repressor elements, can also be used to unlink peptide expression from surface expression.

Additional controls exist as well and are described below.

30 The vector used for anti-sense strand oligonucleotide portions, M13IX22, (Figure 3A), contains the expression elements for the peptide fusion proteins. Upstream and in frame with the Sac I and Eco RI sites in this vector is a leader sequence for surface expression.

A ribosome binding site and Lac Z promoter/operator elements are present for transcription and translation of the peptide fusion proteins.

Both vectors contain a pair of Fok I restriction enzyme sites (Figure 3 A and B) for joining together two precursor oligonucleotide portions and their vector sequences. One site is located at the ends of each precursor oligonucleotide which is to be joined. The second Fok I site within the vectors is located at the end of the vector sequences which are to be joined. The 5' overhang of this second Fok I site has been altered to encode a sequence which is not found in the overhangs produced at the first Fok I site within the oligonucleotide portions. The two sites allow the cleavage of each circular vector into two portions and subsequent ligation of essential components within each vector into a single circular vector where the two oligonucleotide precursor portions form a contiguous sequence (Figure 3C). Non-compatible overhangs produced at the two Fok I sites allows optimal conditions to be selected for performing concatemerization or circularization reactions for joining the two vector portions. Such selection of conditions can be used to govern the reaction order and therefore increase the efficiency of joining.

Fok I is a restriction enzyme whose recognition sequence is distal to the point of cleavage. Distal placement of the recognition sequence in its location to the cleavage point is important since if the two were superimposed within the oligonucleotide portions to be combined, it would lead to an invariant codon sequence at the juncture. To alleviate the formation of invariant codons at the juncture, Fok I recognition sequences can be placed outside of the random codon sequence and still

be used to restrict within the random sequence. Subsequent annealing of the single-strand overhangs produced by Fok I and ligation of the two oligonucleotide precursor portions allows the juncture to be formed. A variety of restriction enzymes restrict DNA by this mechanism and can be used instead of Fok I to join precursor oligonucleotides without creating invariant codon sequences. Such enzymes include, for example, Alw I, Bbu I, Bsp MI, Hga I, Hph I, Mbo II, Mnl I, Ple I and Sfa NI. One skilled in the art knows how to substitute Fok I recognition sequences for alternative enzyme recognition sequences such as those above, and use the appropriate enzyme for joining precursor oligonucleotide portions.

Although the sequences of the precursor oligonucleotides are random and will invariably have oligonucleotides within the two precursor populations whose sequences are sufficiently complementary to anneal after cleavage, the efficiency of annealing can be increased by insuring that the single-strand overhangs within one precursor population will have a complementary sequence within the second precursor population. This can be accomplished by synthesizing a non-degenerate series of known sequences at the Fok I cleavage site coding for each of the twenty amino acids. Since the Fok I cleavage site contains a four base overhang, forty different sequences are needed to randomly encode all twenty amino acids. For example, if two precursor populations of ten codons in length are to be combined, then after the ninth codon position is synthesized, the mixed population of supports are divided into forty reaction vessels for each of the populations and complementary sequences for each of the corresponding reaction vessels between populations are independently synthesized. The sequences are shown in Tables III and

VI of Example I where the oligonucleotides on columns 1R through 40R form complementary overhangs with the oligonucleotides on the corresponding columns 1L through 40L once cleaved. The degenerate X positions in Table VI  
5 are necessary to maintain the reading frame once the precursor oligonucleotide portions are joined. However, use of restriction enzymes which produce a blunt end, such as Mnl I can be alternatively used in place of Fok I to alleviate the degeneracy introduced in maintaining the  
10 reading frame.

The last feature exhibited by each of the vectors is an amber stop codon located in an essential coding sequence within the vector portion lost during combining (Figure 3C). The amber stop codon is present to select  
15 for viable phage produced from only the proper combination of precursor oligonucleotides and their vector sequences into a single vector species. Other non-sense mutations or selectable markers can work as well.

20 The combining step randomly brings together different precursor oligonucleotides within the two populations into a single vector (Figure 3C; M13IX). The vector sequences donated from each independent vector, M13IX22 and M13IX42, are necessary for production of  
25 viable phage. Also, since the expression elements are contained in M13IX22 and the gVIII sequences are contained in M13IX42, expression of functional gVIII-peptide fusion proteins cannot be accomplished until the sequences are linked as shown in M13IX.

30 The combining step is performed by restricting each population of vectors containing randomized oligonucleotides with Fok I, mixing and ligating (Figure 3C). Any vectors generated which contain an amber stop

codon will not produce viable phage when introduced into a non-suppressor strain (Figure 3D). Therefore, only the sequences which do not contain an amber stop codon will make up the final population of vectors contained in the 5 library. These vector sequences are the sequences required for surface expression of randomized peptides. By analogous methodology, more than two vector portions can be combined into a single vector which expresses random peptides.

10       The invention provides for a method of selecting peptides capable of being bound by a ligand binding protein from a population of random peptides by (a) operationally linking a diverse population of first oligonucleotides having a desirable bias of random codon 15 sequences to a first vector; (b) operationally linking a diverse population of second oligonucleotides having a desirable bias of random codon sequences to a second vector; (c) combining the vector products of steps (a) and (b) under conditions where said populations of first 20 and second oligonucleotides are joined together into a population of combined vectors; (d) introducing said population of combined vectors into a compatible host under conditions sufficient for expressing said population of random peptides; and (e) determining the 25 peptides which bind to said binding protein. The invention also provides for determining the encoding nucleic acid sequence of such peptides as well.

Surface expression of the random peptide library is performed in an amber suppressor strain. As described 30 above, the amber stop codon between the random codon sequence and the gVIII sequence unlinks the two components in a non-suppressor strain. Isolating the phage produced from the non-suppressor strain and infecting a suppressor strain will link the random codon

sequences to the gVIII sequence during expression (Figure 3E). Culturing the suppressor strain after infection allows the expression of all peptide species within the library as gVIII-peptide fusion proteins. Alternatively, 5 the DNA can be isolated from the non-suppressor strain and then introduced into a suppressor strain to accomplish the same effect.

The level of expression of gVIII-peptide fusion proteins can additionally be controlled at the 10 transcriptional level. The gVIII-peptide fusion proteins are under the inducible control of the Lac Z promoter/operator system. Other inducible promoters can work as well and are known by one skilled in the art. For high levels of surface expression, the suppressor 15 library is cultured in an inducer of the Lac Z promoter such as isopropylthio- $\beta$ -galactoside (IPTG). Inducible control is beneficial because biological selection against non-functional gVIII-peptide fusion proteins can be minimized by culturing the library under non- 20 expressing conditions. Expression can then be induced only at the time of screening to ensure that the entire population of oligonucleotides within the library are accurately represented on the phage surface. Also this can be used to control the valency of the peptide on the 25 phage surface.

The surface expression library is screened for specific peptides which bind ligand binding proteins by standard affinity isolation procedures. Such methods include, for example, panning, affinity chromatography 30 and solid phase blotting procedures. Panning as described by Parmley and Smith, Gene 73:305-318 (1988), which is incorporated herein by reference, is preferred because high titers of phage can be screened easily, quickly and in small volumes. Furthermore, this

procedure can select minor peptide species within the population, which otherwise would have been undetectable, and amplified to substantially homogenous populations. The selected peptide sequences can be determined by 5 sequencing the nucleic acid encoding such peptides after amplification of the phage population.

The invention provides a plurality of prokaryotic cells containing a diverse population of oligonucleotides having a desirable bias of random codon sequences that 10 are operationally linked to expression sequences. The invention provides for methods of constructing such populations of cells as well.

Random oligonucleotides synthesized by any of the methods described previously can also be expressed on the 15 surface of filamentous bacteriophage, such as M13, for example, without the joining together of precursor oligonucleotides. A vector such as that shown in Figure 4, M13IX30, can be used. This vector exhibits all the functional features of the combined vector shown in 20 Figure 3C for surface expression of gVIII-peptide fusion proteins. The complete nucleotide sequence for M13IX30 (SEQ ID NO: 3) is shown in Figure 7.

M13IX30 contains a wild type gVIII for phage viability and a pseudo gVIII sequence for peptide 25 fusions. The vector also contains in frame restriction sites for cloning random peptides. The cloning sites in this vector are Xho I, Stu I and Spe I. Oligonucleotides should therefore be synthesized with the appropriate complementary ends for annealing and ligation or 30 insertional mutagenesis. Alternatively, the appropriate termini can be generated by PCR technology. Between the restriction sites and the pseudo gVIII sequence is an in-frame amber stop codon, again, ensuring complete

viability of phage in constructing and manipulating the library. Expression and screening is performed as described above for the surface expression library of oligonucleotides generated from precursor portions.

5        Thus, the invention provides a method of selecting peptides capable of being bound by a ligand binding protein from a population of random peptides by (a) operationally linking a diverse population of oligonucleotides having a desirable bias of random codon 10 sequences to expression elements; (b) introducing said population of vectors into a compatible host under conditions sufficient for expressing said population of random peptides; and (c) determining the peptides which bind to said binding protein. Also provided is a method 15 for determining the encoding nucleic acid sequence of such selected peptides.

The following examples are intended to illustrate, but not limit the invention.

20                          EXAMPLE I

Isolation and Characterization of Peptide Ligands  
Generated Right and Left Half Random Oligonucleotides

*SUB  
C3*

This example shows the synthesis of random oligonucleotides and the construction and expression of 25 surface expression libraries of the encoded randomized peptides. The random peptides of this example derive from the mixing and joining together of two random oligonucleotides. Also demonstrated is the isolation and characterization of peptide ligands and their 30 corresponding nucleotide sequence for specific binding proteins.

Synthesis of Random Oligonucleotides

The synthesis of two randomized oligonucleotides which correspond to smaller portions of a larger randomized oligonucleotide is shown below. Each of the  
5 two smaller portions make up one-half of the larger oligonucleotide. The population of randomized oligonucleotides constituting each half are designated the right and left half. Each population of right and left halves are ten codons in length with twenty random  
10 codons at each position. The right half corresponds to the sense sequence of the randomized oligonucleotides and encode the carboxy terminal half of the expressed peptides. The left half corresponds to the anti-sense sequence of the randomized oligonucleotides and encode  
15 the amino terminal half of the expressed peptides. The right and left halves of the randomized oligonucleotide populations are cloned into separate vector species and then mixed and joined so that the right and left halves come together in random combination to produce a single  
20 expression vector species which contains a population of randomized oligonucleotides twenty codons in length. Electroporation of the vector population into an appropriate host produces filamentous phage which express the random peptides on their surface.

25 The reaction vessels for oligonucleotide synthesis were obtained from the manufacturer of the automated synthesizer (Millipore, Burlington, MA; supplier of MilliGen/Biosearch Cyclone Plus Synthesizer). The vessels were supplied as packages containing empty  
30 reaction columns (1  $\mu$ mole), frits, crimps and plugs (MilliGen/Biosearch catalog # GEN 860458). Derivatized and underivatized control pore glass, phosphoramidite nucleotides, and synthesis reagents were also obtained from MilliGen/Biosearch. Crimper and decrimper tools

were obtained from Fisher Scientific Co., Pittsburgh, PA (Catalog numbers 06-406-20 and 06-406-25A, respectively).

Ten reaction columns were used for right half synthesis of random oligonucleotides ten codons in length. The oligonucleotides have 5 monomers at their 3' end of the sequence 5'GAGCT3' and 8 monomers at their 5' end of the sequence 5'AATTCCAT3'. The synthesizer was fitted with a column derivatized with a thymine nucleotide (T-column, MilliGen/Bioscience # 0615.50) and was programmed to synthesize the sequences shown in Table I for each of ten columns in independent reaction sets. The sequence of the last three monomers (from right to left since synthesis proceeds 3' to 5') encode the indicated amino acids:

15

Table I

|    | <u>Column</u> | <u>Sequence<br/>(5' to 3')</u> | <u>Amino Acids</u> |
|----|---------------|--------------------------------|--------------------|
| 20 | column 1R     | (T/G) TTGAGCT                  | Phe and Val        |
|    | column 2R     | (T/C) CTGAGCT                  | Ser and Pro        |
|    | column 3R     | (T/C) ATGAGCT                  | Tyr and His        |
|    | column 4R     | (T/C) GTGAGCT                  | Cys and Arg        |
|    | column 5R     | (C/A) TGGAGCT                  | Leu and Met        |
|    | column 6R     | (C/G) AGGAGCT                  | Gln and Glu        |
|    | column 7R     | (A/G) CTGAGCT                  | Thr and Ala        |
|    | column 8R     | (A/G) ATGAGCT                  | Asn and Asp        |
|    | column 9R     | (T/G) GGGAGCT                  | Trp and Gly        |
|    | column 1R     | A(T/A) AGAGCT                  | Ile and Cys        |

where the two monomers in parentheses denote a single monomer position within the codon and indicate that an equal mixture of each monomer was added to the reaction for coupling. The monomer coupling reactions for each

of the 10 columns were performed as recommended by the manufacturer (amidite version S1.06, # 8400-050990, scale 1  $\mu\text{M}$ ). After the last coupling reaction, the columns were washed with acetonitrile and lyophilized to dryness.

5        Following synthesis, the plugs were removed from each column using a decrimper and the reaction products were poured into a single weigh boat. Initially the bead mass increases, due to the weight of the monomers, however, at later rounds of synthesis material is lost.

10      In either case, the material was equalized with underivatized control pore glass and mixed thoroughly to obtain a random distribution of all twenty codon species. The reaction products were then aliquotted into 10 new reaction columns by removing 25 mg of material at a time

15      and placing it into separate reaction columns. Alternatively, the reaction products can be aliquotted by suspending the beads in a liquid that is dense enough for the beads to remain dispersed, preferably a liquid that is equal in density to the beads, and then aliquoting

20      equal volumes of the suspension into separate reaction columns. The lip on the inside of the columns where the frits rest was cleared of material using vacuum suction with a syringe and 25 G needle. New frits were placed onto the lips, the plugs were fitted into the columns and

25      were crimped into place using a crimper.

Synthesis of the second codon position was achieved using the above 10 columns containing the random mixture of reaction products from the first codon synthesis. The monomer coupling reactions for the second codon position are shown in Table II. An A in the first position means that any monomer can be programmed into the synthesizer. At that position, the first monomer position is not coupled by the synthesizer since the software assumes that the monomer is already attached to the column. An A

also denotes that the columns from the previous codon synthesis should be placed on the synthesizer for use in the present synthesis round. Reactions were again sequentially repeated for each column as shown in Table II and the reaction products washed and dried as described above.

Table II

|    | <u>Column</u>   | <u>Sequence<br/>(5' to 3')</u> | <u>Amino Acids</u> |
|----|---|--------------------------------|--------------------|
| 10 | column 1R   | (T/G)TTA                       | Phe and Val        |
|    | column 2R   | (T/C)CTA                       | Ser and Pro        |
|    | column 3R   | (T/C)ATA                       | Tyr and His        |
|    | column 4R   | (T/C)GTA                       | Cys and Arg        |
|    | column 5R   | (C/A)TGA                       | Leu and Met        |
| 15 | column 6R   | (C/G)AGA                       | Gln and Glu        |
|    | column 7R   | (A/G)CTA                       | Thr and Ala        |
|    | column 8R   | (A/G)ATA                       | Asn and Asp        |
|    | column 9R   | (T/G)GGA                       | Trp and Gly        |
|    | column 10R  | A(T/A)AA                       | Ile and Cys        |
| 20 | Randomization of the second codon position was achieved by removing the reaction products from each of the columns and thoroughly mixing the material. The material was again divided into new reaction columns and prepared for monomer coupling reactions as described above. |                                |                    |
| 25 | Random synthesis of the next seven codons (positions 3 through 9) proceeded identically to the cycle described above for the second codon position and again used the monomer sequences of Table II. Each of the newly repacked columns containing the random mixture of        |                                |                    |
| 30 | reaction products from synthesis of the previous codon position was used for the synthesis of the subsequent codon position. After synthesis of the codon at position   |                                |                    |

nine and mixing of the reaction products, the material was divided and repacked into 40 different columns and the monomer sequences shown in Table III were coupled to each of the 40 columns in independent reactions. The 5 oligonucleotides from each of the 40 columns were mixed once more and cleaved from the control pore glass as recommended by the manufacturer.

Table III

|    | <u>Column</u> | <u>Sequence (5' to 3')</u> |
|----|---------------|----------------------------|
| 10 | column 1R     | AATTCTTTA                  |
|    | column 2R     | AATTCTGTTA                 |
|    | column 3R     | AATTCGTTA                  |
|    | column 4R     | AATTCGGTTA                 |
|    | column 5R     | AATTCTTCTA                 |
| 15 | column 6R     | AATTCTCCTA                 |
|    | column 7R     | AATTCGTCTA                 |
|    | column 8R     | AATTCGCCTA                 |
|    | column 9R     | AATTCTTATA                 |
|    | column 10R    | AATTCTCATA                 |
| 20 | column 11R    | AATTCGTATA                 |
|    | column 12R    | AATTCGCATA                 |
|    | column 13R    | AATTCTTGTA                 |
|    | column 14R    | AATTCTCGTA                 |
|    | column 15R    | AATTCGTGTA                 |
| 25 | column 16R    | AATTCGCGTA                 |
|    | column 17R    | AATTCTCTGA                 |
|    | column 18R    | AATTCTATGA                 |
|    | column 19R    | AATTCGCTGA                 |
|    | column 20R    | AATTCGATGA                 |
| 30 | column 21R    | AATTCTCAGA                 |
|    | column 22R    | AATTCTGAGA                 |
|    | column 23R    | AATTCGCAGA                 |
|    | column 24R    | AATTCGGAGA                 |
|    | column 25R    | AATTCTACTA                 |

|    |            |                     |
|----|------------|---------------------|
|    | column 26R | AATTCTG <u>CTA</u>  |
|    | column 27R | AATTC <u>GACTA</u>  |
|    | column 28R | AATT <u>CGGCTA</u>  |
|    | column 29R | AATT <u>CTAATA</u>  |
| 5  | column 30R | AATT <u>CTGATA</u>  |
|    | column 31R | AATT <u>CGAATA</u>  |
|    | column 32R | AATT <u>CGGATA</u>  |
|    | column 33R | AATT <u>CTTGGA</u>  |
|    | column 34R | AATT <u>CTGGGA</u>  |
| 10 | column 35R | AATT <u>CGTGGGA</u> |
|    | column 36R | AATT <u>CGGGGA</u>  |
|    | column 37R | AATT <u>CTATAAA</u> |
|    | column 38R | AATT <u>CTAAAA</u>  |
|    | column 39R | AATT <u>CGATAAA</u> |
| 15 | column 40R | AATT <u>CGAAAA</u>  |

Left half synthesis of random oligonucleotides proceeded similarly to the right half synthesis. This half of the oligonucleotide corresponds to the anti-sense sequence of the encoded randomized peptides. Thus, the complementary sequence of the codons in Tables I through III are synthesized. The left half oligonucleotides also have 5 monomers at their 3' end of the sequence 5'GAGCT3' and 8 monomers at their 5' end of the sequence 25 5'AATTCCAT3'. The rounds of synthesis, washing, drying, mixing, and dividing are as described above.

For the first codon position, the synthesizer was fitted with a T-column and programmed to synthesize the sequences shown in Table IV for each of ten columns in 30 independent reaction sets. As with right half synthesis, the sequence of the last three monomers (from right to left) encode the indicated amino acids:

Table IV

|    | <u>Column</u> | <u>Sequence<br/>(5' to 3')</u> | <u>Amino Acids</u> |
|----|---------------|--------------------------------|--------------------|
| 5  | column 1L     | AA(A/C)GAGCT                   | Phe and Val        |
|    | column 2L     | AG(A/G)GAGCT                   | Ser and Pro        |
|    | column 3L     | AT(A/G)GAGCT                   | Tyr and His        |
|    | column 4L     | AC(A/G)GAGCT                   | Cys and Arg        |
|    | column 5L     | CA(G/T)GAGCT                   | Leu and Met        |
|    | column 6L     | CT(G/C)GAGCT                   | Gln and Glu        |
| 10 | column 7L     | AG(T/C)GAGCT                   | Thr and Ala        |
|    | column 8L     | AT(T/C)GAGCT                   | Asn and Asp        |
|    | column 9L     | CC(A/C)GAGCT                   | Trp and Gly        |
|    | column 10L    | T(A/T)TGAGCT                   | Ile and Cys        |

Following washing and drying, the plugs for each column were removed, mixed and aliquotted into ten new reaction columns as described above. Synthesis of the second codon position was achieved using these ten columns containing the random mixture of reaction products from the first codon synthesis. The monomer coupling reactions for the second codon position are shown in Table V.

Table V

|    | <u>Column</u> | <u>Sequence<br/>(5' to 3')</u> | <u>Amino Acids</u> |
|----|---------------|--------------------------------|--------------------|
| 25 | column 1L     | AA(A/C)A                       | Phe and Val        |
|    | column 2L     | AG(A/G)A                       | Ser and Pro        |
|    | column 3L     | AT(A/G)A                       | Tyr and His        |
|    | column 4L     | AC(A/G)A                       | Cys and Arg        |
|    | column 5L     | CA(G/T)A                       | Leu and Met        |
|    | column 6L     | CT(G/C)A                       | Gln and Glu        |
| 30 | column 7L     | AG(T/C)A                       | Thr and Ala        |

|            |                 |             |
|------------|-----------------|-------------|
| column 8L  | <u>AT(T/C)A</u> | Asn and Asp |
| column 9L  | <u>CC(A/C)A</u> | Trp and Gly |
| column 10L | <u>T(A/T)TA</u> | Ile and Cys |

Again, randomization of the second codon position was  
 5 achieved by removing the reaction products from each of  
 the columns and thoroughly mixing the beads. The beads  
 were repacked into ten new reaction columns.

Random synthesis of the next seven codon positions  
 proceeded identically to the cycle described above for  
 10 the second codon position and again used the monomer  
 sequences of Table V. After synthesis of the codon at  
 position nine and mixing of the reaction products, the  
 material was divided and repacked into 40 different  
 15 columns and the monomer sequences shown in Table VI were  
 coupled to each of the 40 columns in independent  
 reactions.

Table VI

|    | <u>Column</u> | <u>Sequence (5' to 3')</u> |
|----|---------------|----------------------------|
| 20 | column 1L     | AATTCCATAAAAXXA            |
|    | column 2L     | AATTCCATAAACXXA            |
|    | column 3L     | AATTCCATAACAXXA            |
|    | column 4L     | AATTCCATAACCXXA            |
|    | column 5L     | AATTCCATAGAAXXA            |
| 25 | column 6L     | AATTCCATAGACXXA            |
|    | column 7L     | AATTCCATAGGAXXA            |
|    | column 8L     | AATTCCATAGGCXXA            |
|    | column 9L     | AATTCCATATAAXXA            |
|    | column 10L    | AATTCCATATACXXA            |
| 30 | column 11L    | AATTCCATATGAXXA            |
|    | column 12L    | AATTCCATATGCXXA            |
|    | column 13L    | AATTCCATACAAXXA            |
|    | column 14L    | AATTCCATACACXXA            |

|    |            |                  |
|----|------------|------------------|
|    | column 15L | AATTCCATACGAXXA  |
|    | column 16L | AATTCCATACGCXXA  |
|    | column 17L | AATTCCATCAGAXXA  |
|    | column 18L | AATTCCATCAGCXXA  |
| 5  | column 19L | AATTCCATCATAXXA  |
|    | column 20L | AATTCCATCATCXXA  |
|    | column 21L | AATTCCATCTGAXXA  |
|    | column 22L | AATTCCATCTGCXXA  |
|    | column 23L | AATTCCATCTCAXXA  |
| 10 | column 24L | AATTCCATCTCCXXA  |
|    | column 25L | AATTCCATAGTAXXA  |
|    | column 26L | AATTCCATAGTCXXA  |
|    | column 27L | AATTCCATAGCAXXA  |
|    | column 28L | AATTCCATAGCCXXA  |
| 15 | column 29L | AATTCCATATTAXXA  |
|    | column 30L | AATTCCATATTCXXA  |
|    | column 31L | AATTCCATATCAXXA  |
|    | column 32L | AATTCCATATCCXXA  |
|    | column 33L | AATTCCATCCAAXXA  |
| 20 | column 34L | AATTCCATCCACXXA  |
|    | column 35L | AATTCCATCCCAXXA  |
|    | column 36L | AATTCCATCCCCXXA  |
|    | column 37L | AATTCCATTATAAXXA |
|    | column 38L | AATTCCATTATCXXA  |
| 25 | column 39L | AATTCCATTTTAXXA  |
|    | column 40L | AATTCCATTTTCXXA  |

The first two monomers denoted by an "X" represent an equal mixture of all four nucleotides at that position. This is necessary to retain a relatively unbiased codon sequence at the junction between right and left half oligonucleotides. The above right and left half random oligonucleotides were cleaved and purified from the supports and used in constructing the surface expression libraries below.

Vector Construction

Two M13-based vectors, M13IX42 (SEQ ID NO: 1) and M13IX22 (SEQ ID NO: 2), were constructed for the cloning and propagation of right and left half populations of random oligonucleotides, respectively. The vectors were specially constructed to facilitate the random joining and subsequent expression of right and left half oligonucleotide populations. Each vector within the population contains one right and one left half oligonucleotide from the population joined together to form a single contiguous oligonucleotide with random codons which is twenty-two codons in length. The resultant population of vectors are used to construct a surface expression library.

M13IX42, or the right-half vector, was constructed to harbor the right half populations of randomized oligonucleotides. M13mp18 (Pharmacia, Piscataway, NJ) was the starting vector. This vector was genetically modified to contain, in addition to the encoded wild type M13 gene VIII already present in the vector: (1) a pseudo-wild type M13 gene VIII sequence with a stop codon (amber) placed between it and an Eco RI-Sac I cloning site for randomized oligonucleotides; (2) a pair of Fok I sites to be used for joining with M13IX22, the left-half vector; (3) a second amber stop codon placed on the opposite side of the vector than the portion being combined with the left-half vector; and (4) various other mutations to remove redundant restriction sites and the amino terminal portion of Lac Z.

The pseudo-wild type M13 gene VIII was used for surface expression of random peptides. The pseudo-wild type gene encodes the identical amino acid sequence as that of the wild type gene; however, the nucleotide

sequence has been altered so that only 63% identity exists between this gene and the encoded wild type gene VIII. Modification of the gene VIII nucleotide sequence used for surface expression reduces the possibility of 5 homologous recombination with the wild type gene VIII contained on the same vector. Additionally, the wild type M13 gene VIII was retained in the vector system to ensure that at least some functional, non-fusion coat protein would be produced. The inclusion of wild type 10 gene VIII therefore reduces the possibility of non-viable phage production from the random peptide fusion genes.

The pseudo-wild type gene VIII was constructed by chemically synthesizing a series of oligonucleotides which encode both strands of the gene. The 15 oligonucleotides are presented in Table VII (SEQ ID NOS: 7 through 16).

TABLE VII

Pseudo-Wild Type Gene VIII Oligonucleotide Series

|    | <u>Top Strand<br/>Oligonucleotides</u> | <u>Sequence (5' to 3')</u>                          |
|----|--|---|
| 20 | VIII 03                                | GATCC TAG GCT GAA GGC GAT<br>GAC CCT GCT AAG GCT GC |
|    | VIII 04                                | A TTC AAT AGT TTA CAG GCA<br>AGT GCT ACT GAG TAC A  |
| 25 | VIII 05                                | TT GGC TAC GCT TGG GCT ATG<br>GTA GTA GTT ATA GTT   |
|    | VIII 06                                | GGT GCT ACC ATA GGG ATT AAA<br>TTA TTC AAA AAG TT   |
|    | VIII 07                                | T ACG AGC AAG GCT TCT TA                            |
| 30 | Bottom Strand                          |   |

Oligonucleotides

|    |         |  |
|----|---------|--|
|    | VIII 08 | AGC TTA AGA AGC CTT GCT CGT<br>AAA CTT TTT GAA TAA TTT |
|    | VIII 09 | AAT CCC TAT GGT AGC ACC AAC<br>TAT AAC TAC TAC CAT     |
| 5  | VIII 10 | AGC CCA AGC GTA GCC AAT GTA<br>CTC AGT AGC ACT TG      |
|    | VIII 11 | C CTG TAA ACT ATT GAA TGC<br>AGC CTT AGC AGG GTC       |
| 10 | VIII 12 | ATC GCC TTC AGC CTA G                                  |

Except for the terminal oligonucleotides VIII 03 (SEQ ID NO: 7) and VIII 08 (SEQ ID NO: 12), the above oligonucleotides (oligonucleotides VIII 04-VIII 07 and 09-12 (SEQ ID NOS: 8 through 11 and 13 through 16)) were 15 mixed at 200 ng each in 10  $\mu$ l final volume and phosphorylated with T4 polynucleotide Kinase (Pharmacia, Piscataway, NJ) with 1 mM ATP at 37°C for 1 hour. The reaction was stopped at 65°C for 5 minutes. Terminal oligonucleotides were added to the mixture and annealed 20 into double-stranded form by heating to 65°C for 5 minutes, followed by cooling to room temperature over a period of 30 minutes. The annealed oligonucleotides were ligated together with 1.0 U of T4 DNA ligase (BRL). The annealed and ligated oligonucleotides yield a double- 25 stranded DNA flanked by a Bam HI site at its 5' end and by a Hind III site at its 3' end. A translational stop codon (amber) immediately follows the Bam HI site. The gene VIII sequence begins with the codon GAA (Glu) two codons 3' to the stop codon. The double-stranded insert 30 was phosphorylated using T4 DNA Kinase (Pharmacia, Piscataway, NJ) and ATP (10 mM Tris-HCl, pH 7.5, 10 mM MgCl<sub>2</sub>) and cloned in frame with the Eco RI and Sac I sites within the M13 polylinker. To do so, M13mp18 was digested with Bam HI (New England Biolabs, Beverley, MA)

and Hind III (New England Biolabs) and combined at a molar ratio of 1:10 with the double-stranded insert. The ligations were performed at 16°C overnight in 1X ligase buffer (50 mM Tris-HCl, pH 7.8, 10 mM MgCl<sub>2</sub>, 20 mM DTT, 1 5 mM ATP, 50 µg/ml BSA) containing 1.0 U of T4 DNA ligase (New England Biolabs). The ligation mixture was transformed into a host and screened for positive clones using standard procedures in the art.

Several mutations were generated within the right-  
10 half vector to yield functional M13IX42. The mutations were generated using the method of Kunkel et al., Meth. Enzymol. 154:367-382 (1987), which is incorporated herein by reference, for site-directed mutagenesis. The reagents, strains and protocols were obtained from a Bio  
15 Rad Mutagenesis kit (Bio Rad, Richmond, CA) and mutagenesis was performed as recommended by the manufacturer.

A Fok I site used for joining the right and left halves was generated 8 nucleotides 5' to the unique Eco  
20 RI site using the oligonucleotide 5'-CTCGAATTCTGACATCCT GGTCA TAGC-3' (SEQ ID NO: 17). The second Fok I site retained in the vector is naturally encoded at position 3547; however, the sequence within the overhang was changed to encode CTTC. Two Fok I sites were removed  
25 from the vector at positions 239 and 7244 of M13mp18 as well as the Hind III site at the end of the pseudo gene VIII sequence using the mutant oligonucleotides 5'- CATTGGCAGATGGCTTAGA -3' (SEQ ID NO: 18) and 5'- TAGCATTAAACGTCCAATA-3' (SEQ ID NO: 19), respectively. New  
30 Hind III and Mlu I sites were also introduced at position 3919 and 3951 of M13IX42. The oligonucleotides used for this mutagenesis had the sequences 5'- ATATATTTAGTAAGCTTCATCTTCT-3' (SEQ ID NO: 20) and 5'- GACAAAGAACGCGTGAAACTTT-3' (SEQ ID NO: 21), respectively.

The amino terminal portion of Lac Z was deleted by oligonucleotide-directed mutagenesis using the mutant oligonucleotide 5'-GCGGGCCTTCGCTATTGCTTAAGAAGCCTTGCT-3' (SEQ ID NO: 22). This deletion also removed a third 5 M13mp18 derived Fok I site. The distance between the Eco RI and Sac I sites was increased to ensure complete double digestion by inserting a spacer sequence. The spacer sequence was inserted using the oligonucleotide 5'-TTCAGCCTAGGATCCGCCGAGCTCTCCTACCTGCGAATTCTGTACATCC-3' 10 (SEQ ID NO: 23). Finally, an amber stop codon was placed at position 4492 using the mutant oligonucleotide 5'-TGGATTATACTTCTA AATAATGGA-3' (SEQ ID NO: 24). The amber stop codon is used as a biological selection to ensure the proper recombination of vector sequences to bring 15 together right and left halves of the randomized oligonucleotides. In constructing the above mutations, all changes made in a M13 coding region were performed such that the amino acid sequence remained unaltered. It should be noted that several mutations within M13mp18 20 were found which differed from the published sequence. Where known, these sequence differences are recorded herein as found and therefore may not correspond exactly to the published sequence of M13mp18.

The sequence of the resultant vector, M13IX42, is 25 shown in Figure 5 (SEQ ID NO: 1). Figure 3A also shows M13IX42 where each of the elements necessary for producing a surface expression library between right and left half randomized oligonucleotides is marked. The sequence between the two Fok I sites shown by the arrow 30 is the portion of M13IX42 which is to be combined with a portion of the left-half vector to produce random oligonucleotides as fusion proteins of gene VIII.

M13IX22, or the left-half vector, was constructed to harbor the left half populations of randomized

oligonucleotides. This vector was constructed from M13mp19 (Pharmacia, Piscataway, NJ) and contains: (1) Two Fok I sites for mixing with M13IX42 to bring together the left and right halves of the randomized  
5 oligonucleotides; (2) sequences necessary for expression such as a promoter and signal sequence and translation initiation signals; (3) an Eco RI-Sac I cloning site for the randomized oligonucleotides; and (4) an amber stop codon for biological selection in bringing together right  
10 and left half oligonucleotides.

Of the two Fok I sites used for mixing M13IX22 with M13IX42, one is naturally encoded in M13mp18 and M13mp19 (at position 3547). As with M13IX42, the overhang within this naturally occurring Fok I site was changed to  
15 CTTC. The other Fok I site was introduced after construction of the translation initiation signals by site-directed mutagenesis using the oligonucleotide 5'-TAACACTCATTCCGGATGGAATTCTGGAGTCTGGGT-3' (SEQ ID NO: 25).

The translation initiation signals were constructed  
20 by annealing of overlapping oligonucleotides as described above to produce a double-stranded insert containing a 5' Eco RI site and a 3' Hind III site. The overlapping oligonucleotides are shown in Table VIII (SEQ ID NOS: 26 through 34) and were ligated as a double-stranded insert  
25 between the Eco RI and Hind III sites of M13mp18 as described for the pseudo gene VIII insert. The ribosome binding site (AGGAGAC) is located in oligonucleotide 015 (SEQ ID NO: 26) and the translation initiation codon (ATG) is the first three nucleotides of oligonucleotide  
30 016 (SEQ ID NO: 27).

TABLE VIII

Oligonucleotide Series for Construction of  
Translation Signals in M13IX22

|    | <u>Oligonucleotide</u> | <u>Sequence (5' to 3')</u>      |
|----|------------------------|---------------------------------|
| 5  | 015                    | AATT C GCC AAG GAG ACA GTC AT   |
|    | 016                    | AATG AAA TAC CTA TTG CCT ACG    |
|    | 017                    | GCA GCC GCT GGA TTG TT          |
| 10 | 018                    | ATTA CTC GCT GCC CAA CCA GCC    |
|    |                        | ATG GCC GAG CTC GTG AT          |
|    | 019                    | GACC CAG ACT CCA GATATC CAA CAG |
| 15 | 020                    | GAA TGA GTG TTA AT              |
|    | 021                    | TCT AGA ACG CGT C               |
|    | 022                    | ACGT G ACG CGT TCT AGA AT TAA   |
| 20 | 023                    | CACTCA TTC CTG T                |
|    |                        | TG GAT ATC TGG AGT CTG GGT CAT  |
|    |                        | CAC GAG CTC GGC CAT G           |
|    |                        | GC TGG TTG GGC AGC GAG TAA TAA  |
|    |                        | CAA TCC AGC GGC TGC C           |
|    |                        | GT AGG CAA TAG GTA TTT CAT TAT  |
|    |                        | GAC TGT CCT TGG CG              |

Oligonucleotide 017 (SEQ ID NO: 27) contained a Sac I restriction site 67 nucleotides downstream from the ATG codon. The naturally occurring Eco RI site was removed and a new site introduced 25 nucleotides downstream from the Sac I. Oligonucleotides 5'-TGACTGTCTCCTTGGCGTGTGAAATTGTTA-3' (SEQ ID NO: 35) and 5'-TAACACTCATTCCGGATGGAATTCTGGAGTCTGGGT-3' (SEQ ID NO: 36) were used to generate each of the mutations, respectively. An amber stop codon was also introduced at position 3263 of M13mp18 using the oligonucleotide 5'-CAATTTATCCTAAATCTTACCAAC-3' (SEQ ID NO: 37).

In addition to the above mutations, a variety of other modifications were made to remove certain sequences and redundant restriction sites. The LAC Z ribosome binding site was removed when the original Eco RI site in 5 M13mp18 was mutated. Also, the Fok I sites at positions 239, 6361 and 7244 of M13mp18 were likewise removed with mutant oligonucleotides 5'-CATTTCAGATGGCTTACA-3' (SEQ ID NO: 38), 5'-CGAAAGGGGGTGTGCTGCAA-3' (SEQ ID NO: 39) and 5'-TAGCATTAACGTCCAATA-3' (SEQ ID NO: 40), 10 respectively. Again, mutations within the coding region did not alter the amino acid sequence.

The resultant vector, M13IX22, is 7320 base pairs in length, the sequence of which is shown in Figure 6 (SEQ ID NO: 2). The Sac I and Eco RI cloning sites are at 15 positions 6290 and 6314, respectively. Figure 3A also shows M13IX22 where each of the elements necessary for producing a surface expression library between right and left half randomized oligonucleotides is marked.

#### Library Construction

20 Each population of right and left half randomized oligonucleotides from columns 1R through 40R and columns 1L through 40L are cloned separately into M13IX42 and M13IX22, respectively, to create sublibraries of right and left half randomized oligonucleotides. Therefore, a 25 total of eighty sublibraries are generated. Separately maintaining each population of randomized oligonucleotides until the final screening step is performed to ensure maximum efficiency of annealing of right and left half oligonucleotides. The greater 30 efficiency increases the total number of randomized oligonucleotides which can be obtained. Alternatively, one can combine all forty populations of right half oligonucleotides (columns 1R-40R) into one population and

of left half oligonucleotides (columns 1L-40L) into a second population to generate just one sublibrary for each.

For the generation of sublibraries, each of the  
5 above populations of randomized oligonucleotides are cloned separately into the appropriate vector. The right half oligonucleotides are cloned into M13IX42 to generate sublibraries M13IX42.1R through M13IX42.40R. The left half oligonucleotides are similarly cloned into M13IX22  
10 to generate sublibraries M13IX22.1L through M13IX22.40L. Each vector contains unique Eco RI and Sac I restriction enzyme sites which produce 5' and 3' single-stranded overhangs, respectively, when digested. The single strand overhangs are used for the annealing and ligation  
15 of the complementary single-stranded random oligonucleotides.

The randomized oligonucleotide populations are cloned between the Eco RI and Sac I sites by sequential digestion and ligation steps. Each vector is treated  
20 with an excess of Eco RI (New England Biolabs) at 37°C for 2 hours followed by addition of 4-24 units of calf intestinal alkaline phosphatase (Boehringer Mannheim, Indianapolis, IN). Reactions are stopped by phenol/chloroform extraction and ethanol precipitation.  
25 The pellets are resuspended in an appropriate amount of distilled or deionized water ( $dH_2O$ ). About 10 pmol of vector is mixed with a 5000-fold molar excess of each population of randomized oligonucleotides in 10  $\mu l$  of 1X ligase buffer (50 mM Tris-HCl, pH 7.8, 10 mM MgCl<sub>2</sub>, 20 mM  
30 DTT, 1 mM ATP, 50  $\mu g/ml$  BSA) containing 1.0 U of T4 DNA ligase (BRL, Gaithersburg, MD). The ligation is incubated at 16°C for 16 hours. Reactions are stopped by heating at 75°C for 15 minutes and the DNA is digested with an excess of Sac I (New England Biolabs) for 2

hours. Sac I is inactivated by heating at 75°C for 15 minutes and the volume of the reaction mixture is adjusted to 300  $\mu$ l with an appropriate amount of 10X ligase buffer and dH<sub>2</sub>O. One unit of T4 DNA ligase (BRL) 5 is added and the mixture is incubated overnight at 16°C. The DNA is ethanol precipitated and resuspended in TE (10 mM Tris-HCl, pH 8.0, 1 mM EDTA). DNA from each ligation is electroporated into XL1 Blue™ cells (Stratagene, La Jolla, CA), as described below, to generate the 10 sublibraries.

E. coli XL1 Blue™ is electroporated as described by Smith et al., Focus 12:38-40 (1990) which is incorporated herein by reference. The cells are prepared by inoculating a fresh colony of XL1s into 5 mls of SOB 15 without magnesium (20 g bacto-tryptone, 5 g bacto-yeast extract, 0.584 g NaCl, 0.186 g KC1, dH<sub>2</sub>O to 1,000 mls) and grown with vigorous aeration overnight at 37°C. SOB without magnesium (500 ml) is inoculated at 1:1000 with the overnight culture and grown with vigorous aeration at 20 37°C until the OD<sub>550</sub> is 0.8 (about 2 to 3 h). The cells are harvested by centrifugation at 5,000 rpm (2,600 x g) in a GS3 rotor (Sorvall, Newtown, CT) at 4°C for 10 minutes, resuspended in 500 ml of ice-cold 10% (v/v) sterile glycerol and centrifuged and resuspended a second 25 time in the same manner. After a third centrifugation, the cells are resuspended in 10% sterile glycerol at a final volume of about 2 ml, such that the OD<sub>550</sub> of the suspension is 200 to 300. Usually, resuspension is achieved in the 10% glycerol that remains in the bottle 30 after pouring off the supernate. Cells are frozen in 40  $\mu$ l aliquots in microcentrifuge tubes using a dry ice-ethanol bath and stored frozen at -70°C.

Frozen cells are electroporated by thawing slowly on ice before use and mixing with about 10 pg to 500 ng of vector per 40  $\mu$ l of cell suspension. A 40  $\mu$ l aliquot is placed in an 0.1 cm electroporation chamber (Bio-Rad, 5 Richmond, CA) and pulsed once at 0°C using 200  $\Omega$  parallel resistor, 25  $\mu$ F, 1.88 kV, which gives a pulse length ( $\tau$ ) of ~4 ms. A 10  $\mu$ l aliquot of the pulsed cells are diluted into 1 ml SOC (98 mls SOB plus 1 ml of 2 M MgCl<sub>2</sub>, and 1 ml of 2 M glucose) in a 12- x 75-mm culture tube, 10 and the culture is shaken at 37°C for 1 hour prior to culturing in selective media, (see below).

Each of the eighty sublibraries are cultured using methods known to one skilled in the art. Such methods can be found in Sanbrook et al., Molecular Cloning: A 15 Laboratory Manuel, Cold Spring Harbor Laboratory, Cold Spring Harbor, 1989, and in Ausubel et al., Current Protocols in Molecular Biology, John Wiley and Sons, New York, 1989, both of which are incorporated herein by reference. Briefly, the above 1 ml sublibrary cultures 20 were grown up by diluting 50-fold into 2XYT media (16 g tryptone, 10 g yeast extract, 5 g NaCl) and culturing at 37°C for 5-8 hours. The bacteria were pelleted by centrifugation at 10,000 xg. The supernatant containing phage was transferred to a sterile tube and stored at 25 4°C.

Double strand vector DNA containing right and left half randomized oligonucleotide inserts is isolated from the cell pellet of each sublibrary. Briefly, the pellet is washed in TE (10 mM Tris, pH 8.0, 1 mM EDTA) and 30 recollected by centrifugation at 7,000 rpm for 5' in a Sorval centrifuge (Newtown, CT). Pellets are resuspended in 6 mls of 10% Sucrose, 50 mM Tris, pH 8.0. 3.0 ml of 10 mg/ $\mu$ l lysozyme is added and incubated on ice for 20 minutes. 12 mls of 0.2 M NaOH, 1% SDS is added followed

by 10 minutes on ice. The suspensions are then incubated on ice for 20 minutes after addition of 7.5 mls of 3 M NaOAc, pH 4.6. The samples are centrifuged at 15,000 rpm for 15 minutes at 4°C, RNased and extracted with 5 phenol/chloroform, followed by ethanol precipitation. The pellets are resuspended, weighed and an equal weight of CsCl<sub>2</sub> is dissolved into each tube until a density of 1.60 g/ml is achieved. EtBr is added to 600 µg/ml and the double-stranded DNA is isolated by equilibrium 10 centrifugation in a TV-1665 rotor (Sorval) at 50,000 rpm for 6 hours. These DNAs from each right and left half sublibrary are used to generate forty libraries in which the right and left halves of the randomized oligonucleotides have been randomly joined together.

15        Each of the forty libraries are produced by joining together one right half and one left half sublibrary. The two sublibraries joined together corresponded to the same column number for right and left half random oligonucleotide synthesis. For example, sublibrary 20 M13IX42.1R is joined with M13IX22.1L to produce the surface expression library M13IX.1RL. In the alternative situation where only two sublibraries are generated from the combined populations of all right half synthesis and all left half synthesis, only one surface expression 25 library would be produced.

For the random joining of each right and left half oligonucleotide populations into a single surface expression vector species, the DNAs isolated from each sublibrary are digested an excess of Fok I (New England 30 Biolabs). The reactions are stopped by phenol/chloroform extraction, followed by ethanol precipitation. Pellets are resuspended in dH<sub>2</sub>O. Each surface expression library is generated by ligating equal molar amounts (5-10 pmol) of Fok I digested DNA isolated from corresponding right

and left half sublibraries in 10  $\mu$ l of 1X ligase buffer containing 1.0 U of T4 DNA ligase (Bethesda Research Laboratories, Gaithersburg, MD). The ligations proceed overnight at 16°C and are electroporated into the sup O strain MK30-3 (Boehringer Mannheim Biochemical, (BMB), Indianapolis, IN) as previously described for XL1 cells. Because MK30-3 is sup O, only the vector portions encoding the randomized oligonucleotides which come together will produce viable phage.

10 Screening of Surface Expression Libraries

Purified phage are prepared from 50 ml liquid cultures of XL1 Blue™ cells (Stratagene) which are infected at a m.o.i. of 10 from the phage stocks stored at 4°C. The cultures are induced with 2 mM IPTG.

15 Supernatants from all cultures are combined and cleared by two centrifugations, and the phage are precipitated by adding 1/7.5 volumes of PEG solution (25% PEG-8000, 2.5 M NaCl), followed by incubation at 4°C overnight. The precipitate is recovered by centrifugation for 90 minutes

20 at 10,000 x g. Phage pellets are resuspended in 25 ml of 0.01 M Tris-HCl, pH 7.6, 1.0 mM EDTA, and 0.1% Sarkosyl and then shaken slowly at room temperature for 30 minutes. The solutions are adjusted to 0.5 M NaCl and to a final concentration of 5% polyethylene glycol. After 2

25 hours at 4°C, the precipitates containing the phage are recovered by centrifugation for 1 hour at 15,000 X g. The precipitates are resuspended in 10 ml of NET buffer (0.1 M NaCl, 1.0 mM EDTA, and 0.01 M Tris-HCl, pH 7.6), mixed well, and the phage repelleted by centrifugation at

30 170,000 X g for 3 hours. The phage pellets are subsequently resuspended overnight in 2 ml of NET buffer and subjected to cesium chloride centrifugation for 18 hours at 110,000 X g (3.86 g of cesium chloride in 10 ml of buffer). Phage bands are collected, diluted 7-fold

with NET buffer, recentrifuged at 170,000 X g for 3 hours, resuspended, and stored at 4°C in 0.3 ml of NET buffer containing 0.1 mM sodium azide.

5       Ligand binding proteins used for panning on streptavidin coated dishes are first biotinylated and then absorbed against UV-inactivated blocking phage (see below). The biotinylation reagents are dissolved in dimethylformamide at a ratio of 2.4 mg solid NHS-SS-

10      Biotin (sulfosuccinimidyl 2-(biotinamido)ethyl-1,3'-dithiopropionate; Pierce, Rockford, IL) to 1 ml solvent and used as recommended by the manufacturer. Small-scale reactions are accomplished by mixing 1 µl dissolved reagent with 43 µl of 1 mg/ml ligand binding protein

15      diluted in sterile bicarbonate buffer (0.1 M NaHCO<sub>3</sub>, pH 8.6). After 2 hours at 25°C, residual biotinylation reagent is reacted with 500 µl 1 M ethanolamine (pH adjusted to 9 with HCl) for an additional 2 hours. The entire sample is diluted with 1 ml TBS containing 1 mg/ml

20      BSA, concentrated to about 50 µl on a Centricon 30 ultra-filter (Amicon), and washed on the same filter three times with 2 ml TBS and once with 1 ml TBS containing 0.02% NaN<sub>3</sub> and 7 × 10<sup>12</sup> UV-inactivated blocking phage (see below); the final retentate (60-80 µl) is stored at 4°C.

25      Ligand binding proteins biotinylated with the NHS-SS-Biotin reagent are linked to biotin via a disulfide-containing chain.

UV-irradiated M13 phage were used for blocking binding proteins which fortuitously bound filamentous phage in general. M13mp8 (Messing and Vieira, Gene 19: 262-276 (1982), which is incorporated herein by reference) was chosen because it carries two amber stop codons, which ensure that the few phage surviving irradiation will not grow in the sup O strains used to titer the surface expression libraries. A 5 ml sample

containing  $5 \times 10^{13}$  M13mp8 phage, purified as described above, was placed in a small petri plate and irradiated with a germicidal lamp at a distance of two feet for 7 minutes (flux 150  $\mu\text{W}/\text{cm}^2$ ). NaN<sub>3</sub> was added to 0.02% and 5 phage particles concentrated to  $10^{14}$  particles/ml on a Centricon 30-kDa ultrafilter (Amicon).

For panning, polystyrene petri plates (60 x 15 mm, Falcon; Becton Dickinson, Lincoln Park, NJ) are incubated with 1 ml of 1 mg/ml of streptavidin (BMB) in 0.1 M 10 NaHCO<sub>3</sub> pH 8.6-0.02% NaN<sub>3</sub> in a small, air-tight plastic box overnight in a cold room. The next day streptavidin is removed and replaced with at least 10 ml blocking solution (29 mg/ml of BSA; 3  $\mu\text{g}/\text{ml}$  of streptavidin; 0.1 M NaHCO<sub>3</sub> pH 8.6-0.02% NaN<sub>3</sub>) and incubated at least 1 hour at 15 room temperature. The blocking solution is removed and plates are washed rapidly three times with Tris buffered saline containing 0.5% Tween 20 (TBS-0.5% Tween 20).

Selection of phage expressing peptides bound by the ligand binding proteins is performed with 5  $\mu\text{l}$  (2.7  $\mu\text{g}$  20 ligand binding protein) of blocked biotinylated ligand binding proteins reacted with a 50  $\mu\text{l}$  portion of each library. Each mixture is incubated overnight at 4°C, diluted with 1 ml TBS-0.5% Tween 20, and transferred to a streptavidin-coated petri plate prepared as described 25 above. After rocking 10 minutes at room temperature, unbound phage are removed and plates washed ten times with TBS-0.5% Tween 20 over a period of 30-90 minutes. Bound phage are eluted from plates with 800  $\mu\text{l}$  sterile 30 elution buffer (1 mg/ml BSA, 0.1 M HCl, pH adjusted to 2.2 with glycerol) for 15 minutes and eluates neutralized with 48  $\mu\text{l}$  2 M Tris (pH unadjusted). A 20  $\mu\text{l}$  portion of each eluate is titered on MK30-3 concentrated cells with dilutions of input phage.

A second round of panning is performed by treating 750  $\mu$ l of first eluate from each library with 5 mM DTT for 10 minutes to break disulfide bonds linking biotin groups to residual biotinylated binding proteins. The 5 treated eluate is concentrated on a Centricon 30 ultrafilter (Amicon), washed three times with TBS-0.5% Tween 20, and concentrated to a final volume of about 50  $\mu$ l. Final retentate is transferred to a tube containing 5.0  $\mu$ l (2.7  $\mu$ g ligand binding protein) blocked 10 biotinylated ligand binding proteins and incubated overnight. The solution is diluted with 1 ml TBS-0.5% Tween 20, panned, and eluted as described above on fresh streptavidin-coated petri plates. The entire second eluate (800  $\mu$ l) is neutralized with 48  $\mu$ l 2 M Tris, and 15 20  $\mu$ l is titered simultaneously with the first eluate and dilutions of the input phage.

Individual phage populations are purified through 2 to 3 rounds of plaque purification. Briefly, the second eluate titer plates are lifted with nitrocellulose 20 filters (Schleicher & Schuell, Inc., Keene, NH) and processed by washing for 15 minutes in TBS (10 mM Tris-HCl, pH 7.2, 150 mM NaCl), followed by an incubation with shaking for an additional 1 hour at 37°C with TBS containing 5% nonfat dry milk (TBS-5% NDM) at 0.5 ml/cm<sup>2</sup>. 25 The wash is discarded and fresh TBS-5% NDM is added (0.1 ml/cm<sup>2</sup>) containing the ligand binding protein between 1 nM to 100 mM, preferably between 1 to 100  $\mu$ M. All incubations are carried out in heat-sealable pouches (Sears). Incubation with the ligand binding protein 30 proceeds for 12-16 hours at 4°C with shaking. The filters are removed from the bags and washed 3 times for 35 30 minutes at room temperature with 150 mls of TBS containing 0.1% NDM and 0.2% NP-40 (Sigma, St. Louis, MO). The filters are then incubated for 2 hours at room temperature in antiserum against the ligand binding

protein at an appropriate dilution in TBS-0.5% NDM, washed in 3 changes of TBS containing 0.1% NDM and 0.2% NP-40 as described above and incubated in TBS containing 0.1% NDM and 0.2% NP-40 with  $1 \times 10^6$  cpm of  $^{125}\text{I}$ -labeled  
5 Protein A (specific activity =  $2.1 \times 10^7$  cpm/ $\mu\text{g}$ ). After a washing with TBS containing 0.1% NDM and 0.2% NP-40 as described above, the filters are wrapped in Saran Wrap and exposed to Kodak X-Omat x-ray film (Kodak, Rochester, NY) for 1-12 hours at  $-70^\circ\text{C}$  using Dupont Cronex Lightning  
10 Plus Intensifying Screens (Dupont, Willmington, DE).

Positive plaques identified are cored with the large end of a pasteur pipet and placed into 1 ml of SM (5.8 g NaCl, 2 g  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 50 ml 1 M Tris-HCl, pH 7.5, 5 mls 2% gelatin, to 1000 mls with d $\text{H}_2\text{O}$ ) plus 1-3 drops of  $\text{CHCl}_3$   
15 and incubated at  $37^\circ\text{C}$  2-3 hours or overnight at  $4^\circ\text{C}$ . The phage are diluted 1:500 in SM and 2  $\mu\text{l}$  are added to 300  $\mu\text{l}$  of XL1 cells plus 3 mls of soft agar per  $100\text{ mm}^2$  plate. The XL1 cells are prepared for plating by growing a colony overnight in 10 ml LB (10 g bacto-tryptone, 5 g  
20 bacto-yeast extract, 10 g NaCl, 1000 ml d $\text{H}_2\text{O}$ ) containing 100  $\mu\text{l}$  of 20% maltose and 100  $\mu\text{l}$  of 1 M  $\text{MgSO}_4$ . The bacteria are pelleted by centrifugation at 2000 xg for 10 minutes and the pellet is resuspended gently in 10 mls of 10 mM  $\text{MgSO}_4$ . The suspension is diluted 4-fold by  
25 adding 30 mls of 10 mM  $\text{MgSO}_4$  to give an  $\text{OD}_{600}$  of approximately 0.5. The second and third round screens are identical to that described above except that the plaques are cored with the small end of a pasteur pipet and placed into 0.5 mls SM plus a drop of  $\text{CHCl}_3$  and 1-5  
30  $\mu\text{l}$  of the phage following incubation are used for plating without dilution. At the end of the third round of purification, an individual plaque is picked and the templates prepared for sequencing.

Template Preparation and Sequencing

Templates are prepared for sequencing by inoculating a 1 ml culture of 2XYT containing a 1:100 dilution of an overnight culture of XL1 with an individual plaque. The 5 plaques are picked using a sterile toothpick. The culture is incubated at 37°C for 5-6 hours with shaking and then transferred to a 1.5 ml microfuge tube. 200 µl of PEG solution is added, followed by vortexing and placed on ice for 10 minutes. The phage precipitate is 10 recovered by centrifugation in a microfuge at 12,000 x g for 5 minutes. The supernatant is discarded and the pellet is resuspended in 230 µl of TE (10 mM Tris-HCl, pH 7.5, 1 mM EDTA) by gently pipeting with a yellow pipet tip. Phenol (200 µl) is added, followed by a brief 15 vortex and microfuged to separate the phases. The aqueous phase is transferred to a separate tube and extracted with 200 µl of phenol/chloroform (1:1) as described above for the phenol extraction. A 0.1 volume of 3 M NaOAc is added, followed by addition of 2.5 20 volumes of ethanol and precipitated at -20°C for 20 minutes. The precipitated templates are recovered by centrifugation in a microfuge at 12,000 x g for 8 minutes. The pellet is washed in 70% ethanol, dried and resuspended in 25 µl TE. Sequencing was performed using 25 a Sequenase™ sequencing kit following the protocol supplied by the manufacturer (U.S. Biochemical, Cleveland, OH).

EXAMPLE II

*Sub  
C4*

Isolation and Characterization of Peptide Ligands  
Generated Oligonucleotides Having Random Codons at Two  
Predetermined Positions

5 This example shows the generation of a surface expression library from a population of oligonucleotides having randomized codons. The oligonucleotides are ten codons in length and are cloned into a single vector species for the generation of a M13 gene VIII-based  
 10 surface expression library. The example also shows the selection of peptides for a ligand binding protein and characterization of their encoded nucleic acid sequences.

Oligonucleotide Synthesis

Oligonucleotides were synthesized as described in  
 15 Example I. The synthesizer was programmed to synthesize the sequences shown in Table IX. These sequences correspond to the first random codon position synthesized and 3' flanking sequences of the oligonucleotide which hybridizes to the leader sequence in the vector. The  
 20 complementary sequences are used for insertional mutagenesis of the synthesized population of oligonucleotides.

Table IX

|    | <u>Column</u> | <u>Sequence (5' to 3')</u> |
|----|---------------|----------------------------|
| 25 | column 1      | AA (A/C) GGTTGGTCGGTACCGG  |
|    | column 2      | AG (A/G) GGTTGGTCGGTACCGG  |
|    | column 3      | AT (A/G) GGTTGGTCGGTACCGG  |
|    | column 4      | AC (A/G) GGTTGGTCGGTACCGG  |
|    | column 5      | CA (G/T) GGTTGGTCGGTACCGG  |
|    | column 6      | CT (G/C) GGTTGGTCGGTACCGG  |

|           |                           |
|-----------|---------------------------|
| column 7  | AG (T/C) GGTTGGTCGGTACCGG |
| column 8  | AT (T/C) GGTTGGTCGGTACCGG |
| column 9  | CC (A/C) GGTTGGTCGGTACCGG |
| column 10 | T (A/T) TGGTTGGTCGGTACCGG |

5       The next eight random codon positions were synthesized as described for Table V in Example I. Following the ninth position synthesis, the reaction products were once more combined, mixed and redistributed into 10 new reaction columns. Synthesis of the last  
 10 random codon position and 5' flanking sequences are shown in Table X.

Table X

|    | <u>Column</u> | <u>Sequence (5' to 3')</u>        |
|----|---------------|-----------------------------------|
| 15 | column 1      | AGGATCCGCCGAGCTCAA (A/C) <u>A</u> |
|    | column 2      | AGGATCCGCCGAGCTCAG (A/G) <u>A</u> |
|    | column 3      | AGGATCCGCCGAGCTCAT (A/G) <u>A</u> |
|    | column 4      | AGGATCCGCCGAGCTCAC (A/G) <u>A</u> |
| 20 | column 5      | AGGATCCGCCGAGCTCCA (G/T) <u>A</u> |
|    | column 6      | AGGATCCGCCGAGCTCCT (G/C) <u>A</u> |
|    | column 7      | AGGATCCGCCGAGCTCAG (T/C) <u>A</u> |
|    | column 8      | AGGATCCGCCGAGCTCAT (T/C) <u>A</u> |
|    | column 9      | AGGATCCGCCGAGCTCCC (A/C) <u>A</u> |
|    | column 10     | AGGATCCGCCGAGCTCT (A/T) <u>TA</u> |

The reaction products were mixed once more and the  
 25 oligonucleotides cleaved and purified as recommended by the manufacturer. The purified population of oligonucleotides were used to generate a surface expression library as described below.

Vector Construction

The vector used for generating surface expression libraries from a single oligonucleotide population (i.e., without joining together of right and left half oligonucleotides) is described below. The vector is a M13-based expression vector which directs the synthesis of gene VIII-peptide fusion proteins (Figure 4). This vector exhibits all the functions that the combined right and left half vectors of Example I exhibit.

An M13-based vector was constructed for the cloning and surface expression of populations of random oligonucleotides (Figure 4, M13IX30), M13mp19 (Pharmacia) was the starting vector. This vector was modified to contain, in addition to the encoded wild type M13 gene VIII: (1) a pseudo-wild type gene, gene VIII sequence with an amber stop codon placed between it and the restriction sites for cloning oligonucleotides; (2) Stu I, Spe I and Xho I restriction sites in frame with the pseudo-wild type gVIII for cloning oligonucleotides; (3) sequences necessary for expression, such as a promoter, signal sequence and translation initiation signals; (4) various other mutations to remove redundant restriction sites and the amino terminal portion of Lac Z.

Construction of M13IX30 was performed in four steps. In the first step, a precursor vector containing the pseudo gene VIII and various other mutations was constructed, M13IX01F. The second step involved the construction of a small cloning site in a separate M13mp18 vector to yield M13IX03. In the third step, expression sequences and cloning sites were constructed in M13IX03 to generate the intermediate vector M13IX04B. The fourth step involved the incorporation of the newly constructed sequences from the intermediate vector into

M13IX01F to yield M13IX30. Incorporation of these sequences linked them with the pseudo gene VIII.

Construction of the precursor vector M13IX01F was similar to that of M13IX42 described in Example I except 5 for the following features: (1) M13mp19 was used as the starting vector; (2) the Fok I site 5' to the unique Eco RI site was not incorporated and the overhang at the naturally occurring Fok I site at position 3547 was not changed to 5'-CTTC-3'; (3) the spacer sequence was not 10 incorporated between the Eco RI and Sac I sites; and (4) the amber codon at position 4492 was not incorporated.

In the second step, M13mp18 was mutated to remove the 5' end of Lac Z up to the Lac i binding site and including the Lac Z ribosome binding site and start 15 codon. Additionally, the polylinker was removed and a Mlu I site was introduced in the coding region of Lac Z. A single oligonucleotide was used for these mutagenesis and had the sequence "5'-  
AAACGACGCCAGTGCCAAGTGACGCGTGTGAAATTGTTATCC-3'" (SEQ ID  
20 NO: 41). Restriction enzyme sites for Hind III and Eco RI were introduced downstream of the MluI site using the oligonucleotide "5'-  
GGCGAAAGGAATTCTGCAAGGCGATTAAGCTTGGGTAACGCC-3'" (SEQ ID  
NO: 42). These modifications of M13mp18 yielded the  
25 vector M13IX03.

The expression sequences and cloning sites were introduced into M13IX03 by chemically synthesizing a series of oligonucleotides which encode both strands of the desired sequence. The oligonucleotides are presented 30 in Table XI (SEQ ID NOS: 43 through 50).

TABLE XI  
M13IX30 Oligonucleotide Series

| <u>Top Strand</u> |     | <u>Oligonucleotides</u>   | <u>Sequence (5' to 3')</u>                      |
|-------------------|-----|---|---|
| 5                 | 084 |   | GGCGTTACCCAAGCTTGATGGAGAAAATAAAG                |
|                   | 027 |   | TGAAACAAAGCACTATTGCACTGGCACTCTTACCGT<br>TACCGT  |
|                   | 028 |   | TACTGTTACCCCTGTGACAAAAGCCGCCAGGTCC<br>AGCTGC    |
| 10                | 029 |   | TCGAGTCAGGCCTATTGTGCCAGGGATTGTACTAG<br>TGGATCCG |
| <u>Bottom</u>     |     | <u>Oligonucleotides</u>   | <u>Sequence (5' to 3')</u>                      |
| 15                | 085 |   | TGGCGAAAGGGAATTGGATCCACTAGTACAATCCCTG           |
|                   | 031 |   | GGCACAAATAGGCCTGACTCGAGCAGCTGGACCAGGGCG<br>GCTT |
|                   | 032 |   | TTGTCACAGGGTAAACAGTAACGGTAACGGTAAGTGT<br>GCCA   |
| 20                | 033 |   | GTCGAATAGTGCTTGTTCACTTTATTTCTCCATGT<br>ACAA     |
|                   |     |   |   |
|                   |     |   |   |
| 25                |     | The above oligonucleotides except for the terminal<br>oligonucleotides 084 (SEQ ID NO: 43) and 085 (SEQ ID NO:<br>47) of Table XI were mixed, phosphorylated, annealed and<br>ligated to form a double stranded insert as described in<br>Example I. However, instead of cloning directly into the<br>30 intermediate vector the insert was first amplified by PCR<br>using the terminal oligonucleotides 084 (SEQ ID NO: 43)<br>and 085 (SEQ ID NO: 47) as primers. The terminal<br>oligonucleotide 084 (SEQ ID NO: 43) contains a Hind III<br>site 10 nucleotides internal to its 5' end. |   |

Oligonucleotide 085 (SEQ ID NO: 47) has an Eco RI site at its 5' end. Following amplification, the products were restricted with Hind III and Eco RI and ligated as described in Example I into the polylinker of M13mp18  
5 digested with the same two enzymes. The resultant double stranded insert contained a ribosome binding site, a translation initiation codon followed by a leader sequence and three restriction enzyme sites for cloning random oligonucleotides (Xho I, Stu I, Spe I). The  
10 vector was named M13IX04.

During cloning of the double-stranded insert, it was found that one of the GCC codons in oligonucleotides 028 and its complement in 031 was deleted. Since this deletion did not affect function, the final construct is  
15 missing one of the two GCC codons. Additionally, oligonucleotide 032 contained a GTG codon where a GAG codon was needed. Mutagenesis was performed using the oligonucleotide 5'-TAACGGTAAGAGTGCCAGTGC-3' (SEQ ID NO:  
51) to convert the codon to the desired sequence. The  
20 resultant intermediate vector was named M13IX04B.

The fourth step in constructing M13IX30 involved inserting the expression and cloning sequences from M13IX04B upstream of the pseudo-wild type gVIII in M13IX01F. This was accomplished by digesting M13IX04B  
25 with Dra III and Ban HI and gel isolating the 700 base pair insert containing the sequences of interest. M13IX01F was likewise digested with Dra III and Bam HI. The insert was combined with the double digested vector at a molar ratio of 3:1 and ligated as described in  
30 Example I. It should be noted that all modifications in the vectors described herein were confirmed by sequence analysis. The sequence of the final construct, M13IX30, is shown in Figure 7 (SEQ ID NO: 3). Figure 4 also shows

M13IX30 where each of the elements necessary for surface expression of randomized oligonucleotides is marked.

Library Construction, Screening and Characterization of Encoded Oligonucleotides

5       Construction of an M13IX30 surface expression library is accomplished identically to that described in Example I for sublibrary construction except the oligonucleotides described above are inserted into M13IX30 by mutagenesis instead of by ligation. The 10 library is constructed and propagated on MK30-3 (BMB) and phage stocks are prepared for infection of XLI cells and screening. The surface expression library is screened and encoding oligonucleotides characterized as described in Example I.

15

EXAMPLE III

Isolation and Characterization of Peptide Ligands Generated from Right and Left Half Degenerate Oligonucleotides

This example shows the construction and expression 20 of a surface expression library of degenerate oligonucleotides. The encoded peptides of this example derive from the mixing and joining together of two separate oligonucleotide populations. Also demonstrated is the isolation and characterization of peptide ligands 25 and their corresponding nucleotide sequence for specific binding proteins.

Synthesis of Oligonucleotide Populations

A population of left half degenerate oligonucleotides and a population of right half degenerate oligonucleotides was synthesized using 5 standard automated procedures as described in Example I.

The degenerate codon sequences for each population of oligonucleotides were generated by sequentially synthesizing the triplet NNG/T where N is an equal mixture of all four nucleotides. The antisense sequence 10 for each population of oligonucleotides was synthesized and each population contained 5' and 3' flanking sequences complementary to the vector sequence. The complementary termini was used to incorporate each population of oligonucleotides into their respective 15 vectors by standard mutagenesis procedures. Such procedures have been described previously in Example I and in the Detailed Description. Synthesis of the antisense sequence of each population was necessary since the single-stranded form of the vectors are obtained only 20 as the sense strand.

The left half oligonucleotide population was synthesized having the following sequence: 5'- AGCTCCCGGATGCCTCAGAAGATG (A/CNN)<sub>9</sub>GGCTTTGCCACAGGGG-3' (SEQ ID NO: 52). The right half oligonucleotide population 25 was synthesized having the following sequence: 5'- CAGCCTCGGATCCGCC (A/CNN)<sub>10</sub>ATG (A/C) GAAT-3' (SEQ ID NO. 53). These two oligonucleotide populations when incorporated into their respective vectors and joined together encode a 20 codon oligonucleotide having 19 degenerate positions 30 and an internal predetermined codon sequence.

Vector Construction

Modified forms of the previously described vectors were used for the construction of right and left half sublibraries. The construction of left half sublibraries was performed in an M13-based vector termed M13ED03. This vector is a modified form of the previously described M13IX30 vector and contains all the essential features of both M13IX30 and M13IX22. M13ED03 contains, in addition to a wild type and a pseudo-wild type gene VIII, sequences necessary for expression and two Fok I sites for joining with a right half oligonucleotide sublibrary. Therefore, this vector combines the advantages of both previous vectors in that it can be used for the generation and expression of surface expression libraries from a single oligonucleotide population or it can be joined with a sublibrary to bring together right and left half oligonucleotide populations into a surface expression library.

M13ED03 was constructed in two steps from M13IX30. The first step involved the modification of M13IX30 to remove a redundant sequence and to incorporate a sequence encoding the eight amino-terminal residues of human  $\beta$ -endorphin. The leader sequence was also mutated to increase secretion of the product.

During construction of M13IX04 (an intermediate vector to M13IX30 which is described in Example II), a six nucleotide sequence was duplicated in oligonucleotide 027 (SEQ ID NO: 44) and its complement 032 (SEQ ID NO: 49). This sequence, 5'-TTACCG-3', was deleted by mutagenesis in the construction of M13ED01. The oligonucleotide used for the mutagenesis was 5'-GGTAAACAGTAACGGTAAGAGTGCCAG-3' (SEQ ID NO: 54). The mutation in the leader sequence was generated using the

oligonucleotide 5'-GGGCTTTGCCACAGGGT-3' (SEQ ID NO: 55). This mutagenesis resulted in the A residue at position 6353 of M13IX30 being changed to a G residue. The resultant vector was designated M13IX32.

5 To generate M13ED01, the nucleotide sequence encoding  $\beta$ -endorphin (8 amino acid residues of  $\beta$ -endorphin plus 3 extra amino acid residues) was incorporated after the leader sequence by mutagenesis. The oligonucleotide used had the following sequence: 5'-  
10 AGGGTCATGCCTTCAGCTCCGGATCCCTCAGAAGTCATAAACCCCCCATAGGC  
TTTGCCAC-3' (SEQ ID NO: 56). This mutagenesis also removed some of the downstream sequences through the Spe I site.

The second step in the construction of M13ED03  
15 involved vector changes which put the  $\beta$ -endorphin sequence in frame with the downstream pseudo-gene VIII sequence and incorporated a Fok I site for joining with a sublibrary of right half oligonucleotides. This vector was designed to incorporate oligonucleotide populations  
20 by mutagenesis using sequences complementary to those flanking or overlapping with the encoded  $\beta$ -endorphin sequence. The absence of  $\beta$ -endorphin expression after mutagenesis can therefore be used to measure the mutagenesis frequency. In addition to the above vector  
25 changes, M13ED03 was also modified to contain an amber codon at position 3262 for biological selection during joining of right and left half sublibraries.

The mutations were incorporated using standard mutagenesis procedures as described in Example I. The  
30 frame shift changes and Fok I site were generated using the oligonucleotide 5'-  
TCGCCTTCAGCTCCGGATGCCTCAGAAGCATGAACCCCCATAGGC-3' (SEQ ID NO: 57). The amber codon was generated using the

oligonucleotide 5'-CAATTTATCCTAAATCTTACCAAC-3' (SEQ ID NO: 58). The full sequence of the resultant vector, M13ED03, is provided in Figure 8 (SEQ ID NO: 4).

The construction of right half oligonucleotide  
5 sublibraries was performed in a modified form of the  
M13IX42 vector. The new vector, M13IX421, is identical  
to M13IX42 except that the amber codon between the Eco  
RI-SacI cloning site and the pseudo-gene VIII sequence  
was removed. This change ensures that all expression off  
10 of the Lac Z promoter produces a peptide-gene VIII fusion  
protein. Removal of the amber codon was performed by  
mutagenesis using the following oligonucleotide: 5'-  
GCCTTCAGCCTCGGATCCGCC-3' (SEQ ID NO: 59). The full  
sequence of M13IX421 is shown in Figure 9 (SEQ ID NO: 5).

15 Library Construction, Screening and Characterization of  
Encoded Oligonucleotides

A sublibrary was constructed for each of the  
previously described degenerate populations of  
oligonucleotides. The left half population of  
20 oligonucleotides was incorporated into M13ED03 to  
generate the sublibrary M13ED03.L and the right half  
population of oligonucleotides was incorporated into  
M13IX421 to generate the sublibrary M13IX421.R. Each of  
the oligonucleotide populations were incorporated into  
25 their respective vectors using site-directed mutagenesis  
as described in Example I. Briefly, the nucleotide  
sequences flanking the degenerate codon sequences were  
complementary to the vector at the site of incorporation.  
The populations of nucleotides were hybridized to single-  
30 stranded M13ED03 or M13IX421 vectors and extended with T4  
DNA polymerase to generate a double-stranded circular  
vector. Mutant templates were obtained by uridine  
selection in vivo, as described by Kunkel et al., supra.

Each of the vector populations were electroporated into host cells and propagated as described in Example I.

The random joining of right and left half sublibraries into a single surface expression library was  
5 accomplished as described in Example I except that prior to digesting each vector population with Fok I they were first digested with an enzyme that cuts in the unwanted portion of each vector. Briefly, M13ED03.L was digested with Bgl II (cuts at 7094) and M13IX421.R was digested  
10 with Hind III (cuts at 3919). Each of the digested populations were further treated with alkaline phosphatase to ensure that the ends would not religate and then digested with an excess of Fok I. Ligations, electroporation and propagation of the resultant library  
15 was performed as described in Example I.

The surface expression library was screened for ligand binding proteins using a modified panning procedure. Briefly, 1 ml of the library, about  $10^{12}$  phage  
20 particles, was added to 1-5  $\mu\text{g}$  of the ligand binding protein. The ligand binding protein was either an antibody or receptor globulin (Rg) molecule, Aruffo et al., Cell 61:1303-1313 (1990), which is incorporated herein by reference. Phage were incubated shaking with  
25 affinity ligand at room temperature for 1 to 3 hours followed by the addition of 200  $\mu\text{l}$  of latex beads (Biosite, San Diego, CA) which were coated with goat-antimouse IgG. This mixture was incubated shaking for an additional 1-2 hours at room temperature. Beads were  
30 pelleted for 2 minutes by centrifugation in a microfuge and washed with TBS which can contain 0.1% Tween 20. Three additional washes were performed where the last wash did not contain any Tween 20. The bound phage were then eluted with 200  $\mu\text{l}$  0.1 M Glycine-HCl, pH 2.2 for 15  
35 minutes and the beads were spun down by centrifugation.

The supernatant-containing phage (eluate) was removed and phage exhibiting binding to the ligand binding protein were further enriched by one-to-two more cycles of panning. Typical yields after the first eluate were  
5 about  $1 \times 10^6$  -  $5 \times 10^6$  pfu. The second and third eluate generally yielded about  $5 \times 10^6$  -  $2 \times 10^7$  pfu and  $5 \times 10^7$  -  $1 \times 10^{10}$  pfu, respectively.

The second or third eluate was plated at a suitable density for plaque identification screening and  
10 sequencing of positive clones (i.e., plated at confluence for rare clones and 200-500 plaques/plate if pure plaques were needed). Briefly, plaques grown for about 6 hours at 37°C and were overlaid with nitrocellulose filters that had been soaked in 2 mM IPTG and then briefly dried.  
15 The filters remained on the plaques overnight at room temperature, removed and placed in blocking solution for 1-2 hours. Following blocking, the filters were incubated in 1 µg/ml ligand binding protein in blocking solution for 1-2 hours at room temperature. Goat  
20 antimouse Ig-coupled alkaline phosphatase (Fisher) was added at a 1:1000 dilution and the filters were rapidly washed with 10 mls of TBS or block solution over a glass vacuum filter. Positive plaques were identified after alkaline phosphatase development for detection.  
  
25 Screening of the degenerate oligonucleotide library with several different ligand binding proteins resulted in the identification of peptide sequences which bound to each of the ligands. For example, screening with an antibody to β-endorphin resulted in the detection of  
30 about 30-40 different clones which essentially all had the core amino acid sequence known to interact with the antibody. The sequences flanking the core sequences were different showing that they were independently derived and not duplicates of the same clone. Screening with an

antibody known as 57 gave similar results (i.e., a core consensus sequence was identified but the flanking sequences among the clones were different).

#### EXAMPLE IV

5    Generation of a Left Half Random Oligonucleotide Library

This example shows the synthesis and construction of a left half random oligonucleotide library.

A population of random oligonucleotides nine codons in length was synthesized as described in Example I  
10 except that different sequences at their 5' and 3' ends were synthesized so that they could be easily inserted into the vector by mutagenesis. Also, the mixing and dividing steps for generating random distributions of reaction products was performed by the alternative method  
15 of dispensing equal volumes of bead suspensions. The liquid chosen that was dense enough for the beads to remain dispersed was 100% acetonitrile.

Briefly, each column was prepared for the first coupling reaction by suspending 22 mg (1 $\mu$ mole) of 48  
20  $\mu$ mol/g capacity beads (Genta, San Diego, CA) in 0.5 mls of 100% acetonitrile. These beads are smaller than those described in Example I and are derivatized with a guanine nucleotide. They also do not have a controlled pore size. The bead suspension was then transferred to an  
25 empty reaction column. Suspensions were kept relatively dispersed by gently pipetting the suspension during transfer. Columns were plugged and monomer coupling reactions were performed as shown in Table XII.

Table XII

|    | <u>Column</u> | <u>Sequence<br/>(5' to 3')</u> |
|----|---------------|--------------------------------|
| 5  | column 1L     | AA (A/C) GGCTTTGCCACAGG        |
|    | column 2L     | AG (A/G) GGCTTTGCCACAGG        |
|    | column 3L     | AT (A/G) GGCTTTGCCACAGG        |
|    | column 4L     | AC (A/G) GGCTTTGCCACAGG        |
|    | column 5L     | CA (G/T) GGCTTTGCCACAGG        |
|    | column 6L     | CT (G/C) GGCTTTGCCACAGG        |
| 10 | column 7L     | AG (T/C) GGCTTTGCCACAGG        |
|    | column 8L     | AT (T/C) GGCTTTGCCACAGG        |
|    | column 9L     | CC (A/C) GGCTTTGCCACAGG        |
|    | column 10L    | T (A/T) TGGCTTTGCCACAGG        |

After coupling of the last monomer, the columns were unplugged as described previously and their contents were poured into a 1.5 ml microfuge tube. The columns were rinsed with 100% acetonitrile to recover any remaining beads. The volume used for rinsing was determined so that the final volume of total bead suspension was about 100  $\mu$ l for each new reaction column that the beads would be aliquoted into. The mixture was vortexed gently to produce a uniformly dispersed suspension and then divided, with constant pipetting of the mixture, into equal volumes. Each mixture of beads was then transferred to an empty reaction column. The empty tubes were washed with a small volume of 100% acetonitrile and also transferred to their respective columns. Random codon positions 2 through 9 were then synthesized as described in Example I where the mixing and dividing steps were performed using a suspension in 100% acetonitrile. The coupling reactions for codon positions 2 through 9 are shown in Table XIII.

Table XIII

|    | <u>Column</u> | <u>Sequence<br/>(5' to 3')</u> |
|----|---------------|--------------------------------|
| 5  | column 1L     | AA(A/C)A                       |
|    | column 2L     | AG(A/G)A                       |
|    | column 3L     | AT(A/G)A                       |
|    | column 4L     | AC(A/G)A                       |
|    | column 5L     | CA(G/T)A                       |
|    | column 6L     | CT(G/C)A                       |
| 10 | column 7L     | AG(T/C)A                       |
|    | column 8L     | AT(T/C)A                       |
|    | column 9L     | CC(A/C)A                       |
|    | column 10L    | T(A/T)TA                       |

After coupling of the last monomer for the ninth codon position, the reaction products were mixed and a portion was transferred to an empty reaction column. Columns were plugged and the following monomer coupling reactions were performed: 5'-CGGATGCCTCAGAAGCCCCXXA-3' (SEQ ID NO: 60). The resulting population of random oligonucleotides was purified and incorporated by mutagenesis into the left half vector M13ED04.

M13ED04 is a modified version of the M13ED03 vector described in Example III and therefore contains all the features of that vector. The difference between M13ED03 and M13ED04 is that M13ED04 does not contain the five amino acid sequence (Tyr Gly Gly Phe Met) recognized by anti-β-endorphin antibody. This sequence was deleted by mutagenesis using the oligonucleotide 5'-CGGATGCCTCAGAAGGGCTTTGCCACAGG (SEQ ID NO: 61). The entire nucleotide sequence of this vector is shown in Figure 10 (SEQ ID NO: 6).

Although the invention has been described with reference to the presently preferred embodiment, it should be understood that various modifications can be made without departing from the spirit of the invention.

- 5 Accordingly, the invention is limited only by the claims.